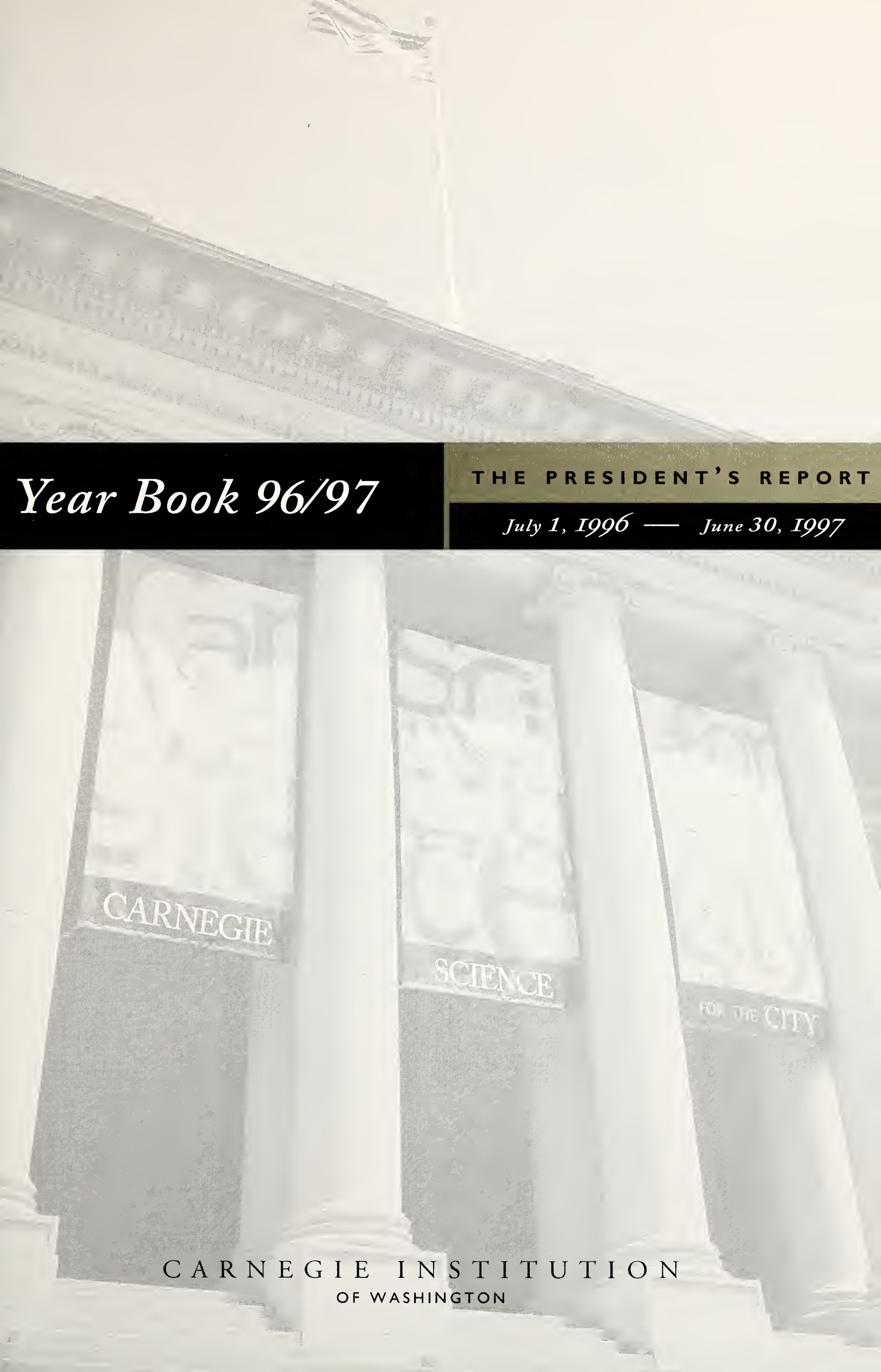
CARNEGIE INSTITUTION
OF WASHINGTON

Extending the Frontiers of Science | **YEAR BOOK 96/97** | *1996–1997*

On the cover: Above: Children from First Light examine a sea urchin.
Below: Banners on the Carnegie Building announce the renovation/restoration project that will provide new classrooms for First Light and the Carnegie Academy for Science Education.



Year Book 96/97

THE PRESIDENT'S REPORT

July 1, 1996 — June 30, 1997

CARNEGIE INSTITUTION
OF WASHINGTON

ABOUT CARNEGIE

. . .TO ENCOURAGE, IN THE BROADEST AND MOST LIBERAL MANNER, INVESTIGATION, RESEARCH, AND DISCOVERY, AND THE APPLICATION OF KNOWLEDGE TO THE IMPROVEMENT OF MANKIND . . .

The Carnegie Institution of Washington was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At five research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

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SCIENCE AND CHILDREN

In September 1997, the inhabitants of the ninety-year-old Carnegie Building at 1530 P St, N.W. moved to temporary quarters in preparation for a major renovation. While the architectural features of the building will be carefully preserved during the renovation, the mechanical, electrical, plumbing, and heating/air conditioning systems will be updated, the auditorium will be restored, and new classrooms created.

Two of the grand forces behind the renovation project—First Light, Carnegie's Saturday science school, and CASE, the institution's science-teaching institute—involve children of the nation's capitol.

Since 1989, elementary school children from the District of Columbia have come to the Carnegie Building during the school year to learn and do science. During the building's renovation, which promises to provide up-to-date laboratory facilities, First Light has been meeting at the institution's Broad Branch Road campus. Highlights from the fall include a trip to the new earth science exhibit at the Natural History Museum and a visit from DTM astronomer Vera Rubin and NASA astronomer Jaylee Mead.

Carnegie newest education venture, the Carnegie Academy for Science Education, or CASE, is succeeding beyond expectation. It was established in 1993 with a grant from the National Science Foundation, and has trained teachers in about half of the elementary schools in Washington, D.C. Nine of those schools have asked CASE directors Chuck James and Inés Cifuentes, and their staff to help them develop a comprehensive science program for their schools. CASE has begun to plan for its second five years, with the intention of adding an elementary-level mathematics program and of increasing the number of schools with CASE-trained teachers. The new, modernized classroom space that will result from the building renovation will make this effort possible.

Left: scenes from First Light and CASE

The President's Commentary

SCIENCE IS A WAY TO TEACH HOW SOMETHING GETS TO BE KNOWN, WHAT IS NOT KNOWN, TO WHAT EXTENT THINGS ARE KNOWN *(for nothing is known absolutely)*, HOW TO HANDLE DOUBT AND UNCERTAINTY, WHAT THE RULES OF EVIDENCE ARE, HOW TO THINK ABOUT THINGS SO THAT JUDGMENTS CAN BE MADE, HOW TO DISTINGUISH TRUTH FROM FRAUD, AND FROM SHOW.

Richard Feynman[1]

The media devotes substantial attention to the state of education in the United States. Anguished reports are frequent. The occasional good news is featured only to allow reflection on the more generally sad state of affairs. Media interest is a sure sign that education is still seen as suffering disastrous problems, as being in 'crisis' condition; if the news was good, education might well disappear from the headlines. President Clinton underscores the troubling assessment through his emphasis and attention.

In truth, the state of education is complex, especially in mathematics and science. It is different in different U.S. states and communities, each of which has its own local school governance, culture, and economic status. And it is different depending on whether it is the professional education of mathematicians and scientists or the education of the general public that is the center of attention.

Although generalizations are dangerous, there is one that seems reasonably well-founded. U.S. colleges, universities, and research institutions are very successful at educating professional scientists. The accomplishments of U.S. scientists in fundamental and applied work are evident all around us, and are frequently displayed in the media and business press. Serious and talented students from all over the world come to this country for training, and remain if they possibly can, recognizing that this is the best place in the world for doing scientific work. It is not difficult to understand why this should be so. University training, especially at the doctoral level, has for many years been predicated on the intimate connection between research and training. This has several very positive consequences. Among the most pertinent are the following: 1) Advanced training is provided through a one-to-one relationship between a senior scientist and student. 2) Students learn by thinking and doing, not by rote. 3) Adequate if not generous funds are available for training because of the national interest in supporting research. The contrast between the success of advanced scientific training and the failure of science education in the K-12 schools reflects the absence of these same three advantages in the schools.

To a very significant extent, it was Vannevar Bush who established the groundwork for our country's current status as the premier educator of professional scientists. His 1945 report, *Science, the Endless Frontier,* stressed the importance not just of scientific research but of scientific training to the economic and strategic position of the U.S. worldwide. He proposed that a single federal agency be responsible for both training and research; this agency came to be the National Science Foundation (NSF). Later, as the National Institutes of Health developed, it too embraced the research/training connection. As president of the Carnegie Institution, Bush adopted the same approach at the Carnegie departments. He initiated a strong program of predoctoral and postdoctoral education, expecting that the research of the

[1] from *The Life and Science of Richard Feynman,* by James Gleick, Pantheon Press, New York, p. 285, 1992.

departments would gain in vigor from such a program, and that the staff scientists, by exposing themselves constantly to the influence of young minds, would be less isolated and more productive. In turn, young scientists would learn from working with leading investigators at a crucial period in their intellectual development. Carnegie departments embraced this philosophy. Today, predoctoral and postdoctoral training are, if anything, more important to the Carnegie labs than they were in Bush's day.

The institution's academic catalog, published biennially, describes our fellowship programs. Funds for postdoctoral fellows come from our general endowment funds and special fellowship funds (e.g., the Wood Fellowship, the McClintock Fellowships, the Starr Fellowship), and from private foundations and federal grants. Providing for additional institutional fellowship funds is always a central concern of the president's fund-raising activities.

Department of Plant Biology director Chris Somerville with postdoctoral fellow Pierre Broun. The intimate connection between research and training at Carnegie and other U.S. institutions rests on intense one-to-one relationships between fellows and their preceptors.

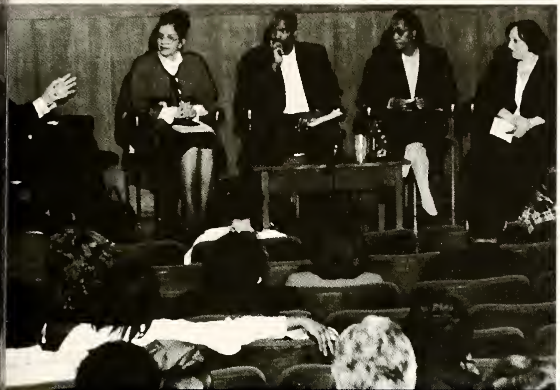
Carnegie is not a degree-granting institution, but our departments still reap benefits from the presence of graduate students. Predoctoral students can and do carry out their thesis research at Carnegie departments under collaborative arrangements between our scientists and their university mentors; degrees are awarded by the home universities. Still, this distinction between Carnegie and the major research universities is significant. For example, a prestigious and generous group of about 350 National Science Foundation Career Awards, including the Presidential Early Career Awards for Scientists and Engineers, exists only for scientists associated with degree-granting institutions. Carnegie scientists are thus ineligible. On Allan Spradling's initiative, we sent a letter to Neal Lane, director of the NSF, requesting reconsideration of the policy. Dr. Lane was attentive in his response. He even came downtown to have lunch with Dr. Spradling (director of our Department of Embryology) and me. But the policy remains unchanged.

PROFESSIONAL SCIENTISTS AND THE SCHOOLS

In recent years, the educational concerns of scientists and scientific institutions have expanded beyond the training of new members of their profession. Increasingly, the community has recognized that the dismal condition of K-12 science and mathematics education is, at least in part, the consequence of its own neglect and disinterest. What passes for science education in most of our schools does not reflect the nature of modern science in either its processes or its logic. Instead of an exciting experience that relates to the real world, school science is too often tied to books, strange new vocabulary, and memorization of poorly understood concepts. Any resemblance to Richard Feynman's vision of what science is all about is accidental. By one estimate, more new words are introduced in first-year high school biology than in first-year French.[2] Both teachers and students are bored by the whole process. The contrast with the enthusiastic, lively spirit in research labs is astonishing, and sad. The only effective and efficient way to change this situation is for scientists to insist on participating directly in the training of teachers, in classroom efforts, and in the preparation of materials such as texts, kits, videos, and software.

The key to a successful effort is having a clear idea of goals. Scientists alone cannot articulate appropriate goals. Scientific considerations must be inte-

[2] *Fulfilling the Promise: Biology Education in the Nation's Schools,* National Academy Press, Washington, D.C., 1990.



At a public forum held at the Carnegie Institution on April 14, Chuck James *(left)* and local teachers discussed the National Science Education Standards, and their impact on D.C. public schools. Also speaking at the event were NAS president Bruce Alberts, NIH National Cancer Institute director Richard Klausner, NASA Administrator Daniel Goldin, and D.C. Public Schools CEO Gen. (Ret.) Julius Becton. The standards form the core of the material taught to D.C. public elementary school teachers at the Carnegie Academy for Science Education (CASE).

grated with teachers' knowledge of pedagogy and childrens' intellectual development. The results must be presented in a way that is both clear and compelling. Thanks to the vision of the National Academy of Sciences, the American Association for the Advancement of Science, and the National Council of Teachers of Mathematics, we now have such guidance in the form of the National Science Education Standards,[3] the Benchmarks for Science Literacy,[4] and the Curriculum and Evaluation Standards[5] (for mathematics), respectively. Working scientists and mathematicians, teachers, and school administrators all contributed to the development of these standards, and they were vetted by large numbers of people. While we can all find in them things that we might prefer to be different, they are sound documents worthy of our attention and adoption by our schools. However, these standards have attracted a fair amount of resistance in various localities and on the national scene. Our nation is very wary of centralized control of education, and many people reject the standards, believing them to be detailed prescriptions of what to teach and how to teach it. But even a brief look at these documents shows otherwise.

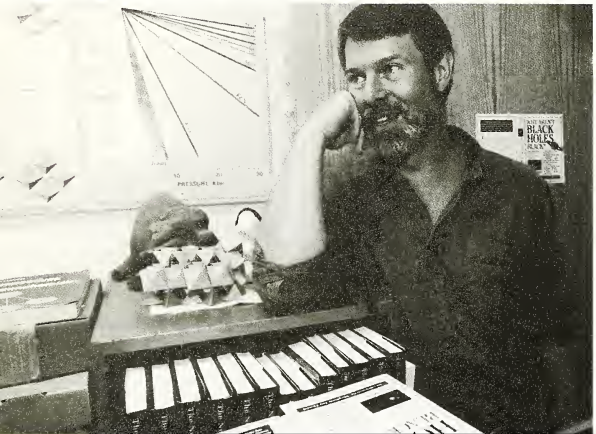
The focus of the science standards, for example, is on broad principles: they outline what a well-educated student should know about the natural world, technology, and related mathematics as she or he progresses from kindergarten through the twelfth grade. They embody the notion of science as a productive response to human curiosity. They are an invitation and guide to local schools to develop their own curricula, choose their own teaching materials, organize their schools, and train their teachers, so that all students, not just those who will become scientists, will be prepared for the personal, social, and career challenges they will experience in an increasingly technological world.

EDUCATIONAL EFFORTS AT CARNEGIE

Many Carnegie scientists years ago recognized the need to become directly involved in science education. Some of them made important contributions to the development and promulgation of the science standards. Also, the institution now has a variety of educational programs encompassing elementary and high school students, undergraduates, and even the general public. We initiated these programs because of their intrinsic value. Now, it seems that they may help us to sustain our long history of success in obtaining federal grant support for our research.

Increasingly, federal granting agencies are using their leverage to encourage scientists to engage in K-12 and undergraduate science and math education. For example, the funding of such large, cutting-edge NSF-sponsored projects as the Center for High Pressure Research (CHiPR), in which Carnegie's Geophysical Lab is a major participant, requires a serious educational component. NASA, too, requires that all proposals, including the coveted Discovery awards (low-priced, unmanned solar system explorations), be accompanied by plans to share the knowledge gained with schools

[3] *National Science Education Standards,* National Academy Press, Washington, D.C., 1996.
[4] *Science for All* (1989) and *Benchmarks for Science Literacy* (1993), American Association for the Advancement of Science, Oxford University Press, New York.
[5] *Curriculum and Evaluation Standards,* The National Council of Teachers of Mathematics, Reston, Virginia, 1989.



Bob Hazen, Geophysical Laboratory staff member, has become a widely known science literacy expert. His most recent book, written with Maxine Singer, is *Why Aren't Black Holes Black?: The Unanswered Questions at the Frontiers of Science,* with an introduction by Stephen Jay Gould. In this book, published in 1997, Hazen and Singer discuss the most pressing scientific questions of the day, noting that we have yet to even recognize what are undoubtedly some of the most profound questions about the universe.

and the general public. Last year, the NSF revised the criteria on which all grant proposals will be judged. There are now only two criteria: scientific quality (that is, excellence) and impact on society.[6] Impact includes how well the proposal promotes teaching and training, broadens participation of underrepresented groups, and enhances the public understanding of science. It is likely that such considerations will be important to other granting agencies before long.

Although the fact that Carnegie does not grant degrees and thus does not have an undergraduate student body adds challenges to meeting these new responsibilities, our long-term and thriving programs for schools and the general public affirm our commitment to ameliorating this national problem.

EDUCATIONAL ACTIVITIES IN THE DEPARTMENTS

The Department of Embryology uses departmental funds to support high school and undergraduate research students in its laboratories, mainly in the summer months. For example, Marnie Halpern has been active in supervising prize-winning high school science fair projects and undergraduate research thesis work for students at Johns Hopkins University and Goucher College. The department also sponsors a voluntary program called Teachers and Researchers in Science Education, initiated ten years ago by Don Brown to provide constructive, sustained links between scientists and teachers in the Baltimore city schools. Staff member Andy Fire has been coordinating this effort for the last five years; several hundred students and about 80 teachers and 80 researchers (from Carnegie and Johns Hopkins) have participated.

For many years, the Geophysical Laboratory sponsored informal summer programs for high school and undergraduate students. The quality of some of these efforts are seen in prior Year Book reports and in the prizes that some of the interns won for their work. In summer 1997, the Lab initiated an NSF-funded Summer Intern Program in Geoscience. Connie Bertka, senior research associate, was the astute and attentive mentor for this ten-week long program, and Charles Prewitt, the director, gave important support and oversight. The students received stipends and travel expenses, and housing was provided through rental of local apartments. The students were assigned to the labs of staff members, who served as mentors for the individual research projects. Besides their own work, the students attended seminars, toured other D.C.-area geoscience facilities, and spent a day visiting with the D.C. teachers attending the Carnegie Academy for Science Education (CASE; described below). The summer was to end in a celebratory symposium and the presentation, by the interns, of their accomplishments. The symposium occurred, but the mood was not celebratory. A few days before, the only high school student in the group, the exceptionally gifted Ben Cooper, was killed in a terrible automobile collision a few blocks from the lab. The driver of the truck that fell atop Ben's car should not have been driving, and the case has become a major local issue centering on the irresponsibility of the motor vehicle authorities. The students, who had formed a close-knit group, were devastated, as were many in the Laboratory. We will be initiating a Benjamin Cooper Fellowship Fund for summer students, to

[6] *Science,* American Association for the Advancement of Science, April 4, 1996, p. 29.

Top: Geophysical Laboratory staff member George Cody with Amymarie Accardi, a college student involved in the 1997 Summer Intern Program in Geoscience. *Below:* Members of the group *(top row, left to right)*: David Lawler, Vincent Lim, Audrey Slesinger, Virginie Pinel, Stephanie Kitchel; *(front row):* Mark Acton, Nora Klein, Amymarie Accardi, Michelle Weinberger, and Alexander Feldman.

honor Ben's memory and to remind us that we are all diminished by the loss of this very promising young scientist.

The Department of Plant Biology, located in our facilities on the campus of Stanford University, has had an especially collegial relationship with Stanford plant biologists for many years. This translates into direct interaction with undergraduates and graduate students, many of whom do their thesis projects in the department's labs. Joe Berry and Chris Field collaborate with their Stanford colleague, Hal Mooney, in an annual undergraduate course in ecology. Stanford undergraduates are engaged in Chris Field's field projects. Interns from the biotechnology program at Foothill College (one of the California state schools) work in several of the labs. Chris and Shauna Somerville are teaching a full-quarter course on plant genetic engineering for freshmen, including students who have no intention of majoring in science. Neil Hoffman is also contributing to the education of nonscience majors with a seminar exploring the controversial issues arising from new developments in biotechnology.

With the arrival of summer, the Department of Terrestrial Magnetism (DTM) welcomes high school and undergraduate students to its labs. Some of these students have won support through national competitions, such as the NASA Planetary Geology Intern Program. Others are supported by departmental or personal funds. Several new plans are under way. Next summer, with a grant from the Dreyfus Foundation, DTM will initiate a Dreyfus Foundation Summer Intern Program in Geochemistry and Cosmochemistry. Also, the newly formed joint DTM/GL/Southern Africa Kaapvaal Craton Project includes educational development for black southern African science students. Introducing disadvantaged students to the potential of a career in science is a challenge in many countries, especially those in southern Africa. The whole problem of appropriate science education is of worldwide concern, even in countries with traditionally strong science efforts.

Our closest foreign tie is of course with Chile, which has been gracious host to the Las Campanas Observatory since 1970. For many years, we sponsored a Chilean student studying for a doctoral degree in astronomy at an American university. The second Carnegie-Chile fellow, Maria Teresa Ruiz, is now a professor at the University of Chile. This year she was awarded her nation's highest scientific honor: the National Science Award. Chilean astronomers are regularly in residence at Las Campanas; indeed, with 10% of the observing time on our telescopes, they make excellent use of the facilities, and many have become valued colleagues for Carnegie astronomers. If there is any "but" to this picture, it is that there are too few Chilean astronomers.

This shortage will be even more acutely felt in the next decade, as the Magellan telescopes, the four ESO 8-meter telescopes, and the U.S. national Gemini telescope see first light. There are simply too few Chilean astronomers to make good use of the share they will have in all of these powerful new instruments. Realizing the need to encourage

Members of the Las Campanas summer school, above, did their own research on the mountain, using telescopes and sophisticated software. The institution will sponsor the school again next summer.

more young Chileans to become astronomers, Carnegie, with substantial support from the Fundacion Andes, initiated an annual summer school in astronomy for Chilean undergraduates interested in the physical sciences. Our contribution includes the time and expertise of Miguel Roth, director of Las Campanas Observatory, and the facilities, including telescope time. Another important contribution was made by Lois Severini and her husband, Henry Gittes, who provided a stipend for a Chilean postdoctoral fellow to help run the school; the rest of the year, this fellow will do research in collaboration with Miguel Roth.

The school takes place on the mountain, and it includes a mini-course in astronomy with lectures by the Las Campanas staff and visiting astronomers, some of them Chilean professors. Most importantly, the students carry out their own research projects; they learn first-hand how to use the telescopes and sophisticated software designed for astronomical analysis. By all accounts, the first session, in February 1997, was a huge success. The ten students, selected from over 100 applicants, barely slept; nights were spent at the telescope and days were devoted to studying and talking astronomy.

SCIENCE FOR THE CITY, WASHINGTON, D.C.

For many years, we have all asked ourselves why our organization is called the Carnegie Institution *of Washington.* True, some of us work in the nation's capital, but much of our activity takes place elsewhere. Is there any significance to our name other than as a reflection of history, particularly Andrew Carnegie's evolving plans for his research institution and his need to distinguish each of his "Carnegie" establishments from the others? In the nearly 100 years since the institution acquired its name, its role in the life of the city has waxed and waned. The city, too, has changed. Presently it is, in a sense, the capital of the world. For U.S. scientists, it is the complex source of decisions about research and research funding; the "science policy establishment" lives here. It is also a late-20th-century urban place, populated in the main by poor, disadvantaged people. Its local government has collapsed (for reasons too numerous and complex to describe here). Tens of thousands of people of many races work in the city, most of them commuting from middle-class suburbs with public schools as good as any in the nation. In contrast, the disadvantaged children in the city are trapped in poor schools that are now struggling to change. How, then, can the Carnegie Institution be, or strive to be, *of Washington?*

In 1930, Carnegie president John Merriam addressed this role in his Year Book report. He wrote: "It is clear that, with our exceptional opportunities, relation to the public involves more than the responsibility merely to conduct researches."[7] As a result of Merriam's concept, our administration building in Washington was enlarged to make room for the Elihu Root Auditorium, and a series of public lectures was planned. But soon after the new wing was completed, during Vannevar Bush's presidency and for the duration of World War II, the building instead became the home of the National Defense Research Committee and its successor, the Office of Scientific Research and

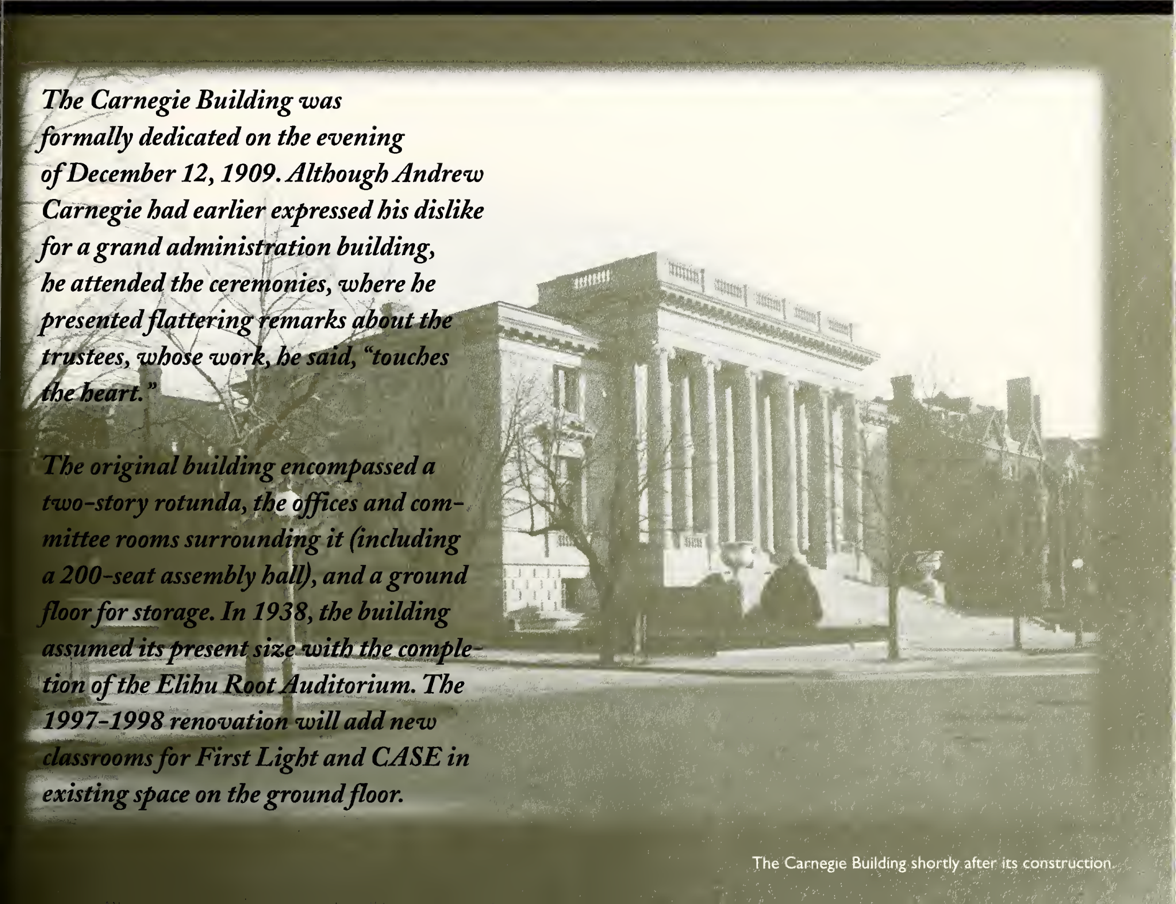
[7] Report of the President, *Carnegie Institution of Washington Year Book 29,* Carnegie Institution, Washington, D.C., 1930.

Development. After the war, the building was only occasionally used for public purposes. Merriam's vision for public programs was forgotten.

By the late 1980s, we were all increasingly aware of the deterioration of U.S. public education in general, and of science and mathematics education in particular. Nowhere was this deficiency more obvious than in the urban centers, including Washington, D.C. Mindful of that *of Washington* in our name, and of the need for scientists to take an active part in righting the situation, we began a series of educational activities in our building all aimed at the local community. We think of them under the umbrella title "Science for the City." Bright banners announcing this motto now hang from the impressive columns on 16th Street.

Our efforts at spreading the excitement of modern science to the general public, including the science policy establishment, are concentrated in the eight Capital Science Lectures we host during the year. The 1997-1998 year marks the eighth season for this free series. (The 1996-1997 lectures are listed on page 76.) It is exciting to watch almost 400 people gather monthly to listen to distinguished and lucid scientists explain things in terms all can understand. We have had talks on AIDs, on buckminsterfullerenes, on how the ear works, on the building of Tibet, on gravity, on Venus and Mars, on animal behavior. The audience is typically nine to 90 in age and seems to want to stay all evening, asking questions.

The children of Washington draw most of our attention. The first activity to be established (in 1989) was First Light, a Saturday science program for D.C. elementary school children. Initially, this program recruited children attending the public schools closest to our building at 16th and P Streets. Now, the children come from all over the city and there is a waiting list. They meet in a ship-



The Carnegie Building was formally dedicated on the evening of December 12, 1909. Although Andrew Carnegie had earlier expressed his dislike for a grand administration building, he attended the ceremonies, where he presented flattering remarks about the trustees, whose work, he said, "touches the heart."

The original building encompassed a two-story rotunda, the offices and committee rooms surrounding it (including a 200-seat assembly hall), and a ground floor for storage. In 1938, the building assumed its present size with the completion of the Elihu Root Auditorium. The 1997-1998 renovation will add new classrooms for First Light and CASE in existing space on the ground floor.

The Carnegie Building shortly after its construction

Carnegie's Capital Science Lecture Series draws an overflow crowd from the Washington, D.C. area.

ping room that was turned into a children's laboratory. Mornings are spent in the lab, lunch is served, and afternoons are a time for exploring science in the city, everywhere from museums to flower shops. The program is free to the children and is supported by local philanthropies, including the Cafritz Foundation and the Fannie Mae Foundation.

Experiments and inquiry characterize the First Light methods. It was these methods, largely the concepts of Charles James, director of First Light from its inception, that attracted the attention of parents and the principal at a local school. With their encouragement, along with the participation of Inés Cifuentes (a seismologist at DTM), and substantial support from the NSF and the Howard Hughes Institute for Medical Research, we established the Carnegie Academy for Science Education. After four years, CASE has trained about 350 D.C. elementary school teachers in First Light methods, using the national standards and the D.C. curriculum as guides. The teachers spend six intensive weeks at CASE, learning scientific content and teaching methods, and doing hands-on experiments. During the school year, CASE staff visits the schools to help teachers put their new insights and skills into practice.

The elegant old Carnegie Building has been a spacious setting for all these activities. No longer is it a mysterious, imposing stone structure on 16th Street. But even as it became a lively center for D.C. residents, its signs of age became more apparent. Primitive air conditioning made CASE summer institutes unpleasant. Poor lighting was a problem. The boilers and elevator needed constant attention. The roof leaked. The lack of basic modern safety measures like sprinklers made it unsafe. Electric wires and computer cables were strung about in unsightly and dangerous ways. So, in September 1997, we moved out to make way for major renovation. Carnegie staff and public programs are in temporary quarters until late spring. The bright "Science for the City" banners will hang throughout the renovation, but the inhabitants of the building are now electricians, masons, plumbers, engineers, plasterers, and removers of hazardous wastes. The second and third floor quarters will be restored to their full elegance, but properly heated and cooled, and protected from fire hazards. The J. Monroe Hewlett murals in the Root auditorium will be cleaned, and modern lighting and audiovisual equipment will be installed. On the ground floor, reorganization of space will make new, bright classrooms for First Light and CASE.

Andrew Carnegie objected when, in 1907, the trustees determined to build the administration building. He wrote: "What I should like to see is the Institution noted for the simplicity of surroundings and the grandeur of its work, not vice versa."[8] Now, 90 years later, we are placing the building in the service of the city's children and thus of the future of the city and nation. We can imagine and hope that our founder would have appreciated the grandeur in this endeavor.

—Maxine F. Singer
November 1997

[8] Letter from Andrew Carnegie to President Robert Woodward, December 1907.

LOSSES


Alfred D. Hershey

We are sad to report the death of **Alfred D. Hershey,** a staff member of the Department of Genetics from 1950 to 1972. A true pioneer of modern genetics, he died on May 22, 1997 at the age of 88. Hershey belonged to a group of scientists known as "the phage group," who established that simple viruses called bacteriophage were ideal model organisms for genetic study. In 1969, he won the Nobel prize for his famous "Waring Blender" experiment, in which he used bacteriophage to demonstrate that DNA, rather than protein, carries a cell's genetic material. Until his retirement in 1972, Hershey continued to research the growth and development of bacterial cells after infection. His work supports much of today's cancer research. Privately, he derived true joy from his work, and was a quiet, gentle presence in the department. It is a presence that has been, and will continue to be, missed.

George M. Temmer, a DTM staff member from 1953 to 1963, died on January 12, 1997 at age 74. A native of Vienna, he emigrated to France and then to the United States, receiving his Ph.D. from the University of California in 1949 with Emilio Segré as his adviser. At DTM, he and Norman Heydenburg were trailblazers in the study of nuclei using Coulomb excitation, in which an accelerated bombarding particle interacts with the target nucleus by means of electromagnetic force. This allowed for investigation of low-energy excited states of atomic nuclei, and ultimately the demonstration that some nuclei have non-spherical shapes. Temmer and Heydenburg established the Nuclear Physics Laboratory at Florida State University. Temmer later became director of a similar organization at Rutgers University.

Ziro Suzuki, a DTM senior fellow from 1962 to 1964 and long-time colleague, died on July 5, 1997 at age 74. Suzuki had been a professor of geophysics at the University of Tohoku.

Leo Haber, a carpenter and maintenance foreman at DTM from 1960 to 1975, died on April 12, 1997.

Benjamin Eric Cooper, a 1997 summer intern at the Geophysical Laboratory, died tragically in a traffic accident on August 12, three days before the conclusion of the internship program. A senior at the Georgetown Day High School in Washington, D.C., he was seventeen years old.

RETIRING

Trustees **Richard Heckert** and **Edward E. David, Jr.** stepped down from the board at the May meeting, and were both appointed trustees emeriti. Heckert was chairman of the board from 1986 until 1992, and David was acting president of the institution, 1987-1988. Both were elected in 1980.

A staff member at the Observatories for 45 years, **Allan Sandage** retired on August 31, 1997. Having established early in his career a practical methodology for determining the age of stellar systems, he is known all over the world for his devel-

opment of a distance scale in the universe. He published *The Hubble Atlas of Galaxies* in 1963, and *The Carnegie Atlas of Galaxies* with John Bedke in 1994. Both works continue to be very much in demand. He remains at the Observatories as staff member emeritus.

John Emler retired from DTM on November 30, 1997 after 19 years of service. Emler, a DTM geochemistry laboratory technician, was known for his ingenuity and versatile skills in electronics, machining, and high-vacuum technology.

Frank Press ended his tenure as the Cecil and Ida Green Senior Fellow at DTM and the Geophysical Laboratory in June 1997 to become a founding member and principal of the Washington Advisory Group. He remains a Carnegie trustee.

Peter de Jonge stepped down in April 1997 as Magellan Project manager.

GAINS


Burton McMurtry

Carnegie welcomes three new trustees: **Burton McMurtry, Suzanne Nora Johnson,** and **Christopher Stone.** Burton McMurtry is a founder and general partner of Technology Venture Investors, a venture capital company in Menlo Park, California that focuses on start-up investments in electronic technology. A native of Texas, McMurtry holds a B.A. and B.S. from Rice University and a Ph.D. in electrical engineering from Stanford. He joined the Carnegie board in December 1996.


Suzanne Nora Johnson

Suzanne Nora Johnson, an investment banker at Goldman, Sachs & Co., also joined the board in December. A partner since 1992, she is now managing director of the worldwide Healthcare Group at Goldman Sachs. She received her B.A. from the University of Southern California and her J.D. from Harvard University.


Christopher Stone

Christopher Stone was elected a trustee in December 1997. As chief executive of Diatech Limited, London, he supervises operating assets, allocates global assets for investment portfolios, monitors specialist investment managers, and supervises activities in plant biotechnology. Stone hails from Scotland; he received his M.A. from the University of Edinburgh.

Andrew McWilliam joined the Observatories as a staff member in July 1997. He received his Ph.D. at the University of Texas in 1988, and has been at the Observatories since 1991 as a research associate, a senior research associate, and the Observatories' first Barbara McClintock Fellow. He is a world leader in the study of the early chemical history of the Galaxy, and carries on the Observatories' long and distinguished tradition of research in that field.

David Ehrhardt joined the Department of Plant Biology as a staff associate in February 1997. He received his Ph.D. from Stanford, where he held his prior position of postdoctoral fellow in Sharon Long's lab. He will be working at Carnegie on problems of cell communication and pattern formation using the model organism *Arabidopsis thaliana*.

The Observatories' **Matt Johns,** formerly Magellan Project lead engineer, became Magellan Project manager.

HONORS

DTM's **George Wetherill** received a National Medal of Science, the highest scientific honor in the nation, in the fall of 1997. Wetherill is known for his contributions to the development of radiometric age-dating techniques and theoretical models simulating the evolution of the inner solar system.

George Wetherill with President Bill Clinton

Photo: Christy Bowe

Embryology staff member **Douglas Koshland's** appointment as a Howard Hughes Medical Institute Investigator began in June 1997. His research focuses on chromosomes during mitosis, and may lead to a better understanding and possible treatment of cancer.

Vera Rubin's nomination to the National Science Board by President Clinton was confirmed by the Senate in early 1997. She received an honorary Doctor of Science degree at the mid-winter commencement of the University of Michigan. In May, she was awarded an honorary Doctor of Humane Letters degree at Georgetown University College of Arts and Sciences commencement, where she delivered the commencement address.

Geophysical Laboratory's **Russell Hemley** and Observatories' **Steve Shectman** were both elected to the American Academy of Arts and Sciences in April 1997. Hemley was also elected a fellow of the American Geophysical Union.

Plant Biology's **Chris Somerville** was awarded an honorary Doctor of Science degree when he presented the convocation address at the University of Alberta in June 1997.

Sean Solomon delivered the 1997 J. Tuzo Wilson Lecture at the University of Toronto in April. He was elected a Fellow of the Geological Society of America in May.

Allan Sandage received the Distinguished Alumni Award from the California Institute of Technology in May 1997.

Embryology staff member **Andy Fire** was honored with the 1997 Maryland Distinguished Young Scientist Award in April 1997 for "inventing methods to analyze and manipulate genes in the *C. elegans* and using them to analyze how muscles develop in embryos."

Yixian Zheng of the Department of Embryology was named a 1997 Pew Scholar by the Pew Charitable Trusts in the Biomedical Sciences.

Maxine Singer received the Centenary Medal when she presented the academic convocation address at the Memorial Sloan-Kettering Cancer Center in May 1997.

The Carnegie Academy for Science Education (CASE) received a special award for "Outstanding Commitment and Support" from D.C. Superintendent Julius Becton, Jr. at an awards ceremony in June 1997.

Former Plant Biology staff member **William Hiesey** was honored at the California Native Grass Association in November 1996 for his collaborative work with David Keck and Jens Clausen on research that revealed the interplay of heredity and the environment in evolution. This work led to the ecological restoration of rangelands.

Former DTM staff member **Stanley Hart,** now at Woods Hole Oceanographic Institution, was awarded the 1997 Harry Hess Medal of the American Geophysical Union.

Former Geophysical Laboratory staff member **Donald H. Lindsay** received the Roebling Medal for distinguished research at the Mineralogical Society of America's meeting in October 1996.

Former Carnegie-Chilean Observatories fellow **Maria Teresa Ruiz** received the National Science Award for Physics and Mathematics, the highest recognition of its kind in Chile, in September 1997.

Former DTM fellow **Prudence Foster** received a Japanese Society for the Promotion of Science Fellowship.

DTM visiting investigator and former fellow **Paul Rydelek** (University of Memphis) has received a Fulbright grant as a senior scholar at the Geophysics Institute of the University of Karlsruhe, Germany, where his research will focus on devastating earthquakes in Romania.

Trustee **William T. Coleman, Jr.** received the George Wickersham Award for 1997 from the Friends of the Library of Congress in February 1997.

Trustee **Sandy Faber** was awarded the Antoinette de Vaucouleurs Medal from the University of Texas, Austin in February 1997. In June, she received an honorary degree from Williams College.

Trustee **Charles Townes** received an honorary doctorate at the University of Pusan in Korea and was made an honorary citizen of the city.

Trustee **William R. Hewlett** and his late partner, David Packard, were honored with the Heinz Awards Chairman's Medal in December 1996.

The Carnegie Institution has received gifts and grants from the following individuals, foundations, corporations, and government agencies during the period from July 1, 1996 to June 30, 1997.

CORPORATIONS AND FOUNDATIONS

$100,000-$1 million

Ahmanson Foundation
Arnold and Mabel Beckman Foundation
Crystal Trust
DDI Corporation
Johnson & Johnson
Kyocera Corporation
Lucille P. Markey Charitable Trust
Andrew W. Mellon Foundation
The John Merck Fund
Ambrose Monell Foundation
Sidney J. Weinberg, Jr. Foundation
The Starr Foundation

$10,000-$99,999

Abbott Laboratories Fund
Fundacion Andes
Cancer Research Fund
Carnegie Institution of Canada/Institution Carnegie du Canada
The Jane Coffin Childs Memorial Fund for Medical Research
Crestlea Foundation Inc.
The Camille and Henry Dreyfus Foundation, Inc.
Exxon Education Foundation
Freddie Mac Foundation
Golden Family Foundation
Philip L. Graham Fund
William Randolph Hearst Foundation
Howard Hughes Foundation
Humana, Inc.
Lampadia Foundation
Life Sciences Research Foundation
Richard Lounsbery Foundation
Fannie Mae Foundation
The G. Harold and Leila Y. Mathers Charitable Foundation
Millipore Foundation
Pew Scholars Program
Pfizer Inc.
Schering-Plough Corporation
Alfred P. Sloan Foundation
The William and Nancy Turner Foundation
The Thomas N. Urban, Jr. and Mary Bright Urban Foundation
Welfare Foundation, Inc.
Whitehead Charitable Foundation

$1,000 to $9,999

The Advisory Board Foundation
The Bristol-Myers Squibb Foundation, Inc.
Computer Sciences Corporation
Eli Lilly and Company Foundation
George F. Jewett, Jr. 1965 Trust
GTE Service Corporation
Richard W. Higgins Foundation
Paul and Annetta Himmelfarb Foundation
Maximilian E. and Marion O. Hoffman Foundation, Inc.
International Human Frontier Science Program
Lubin Family Foundation
Newmont Gold Company
Newmont Mining Corporation
Nina and Ivan Selin Family Foundation
The Ruth and Frank Stanton Fund
The Swig Foundation

Under $1,000

Association of Universities for Research in Astronomy
Guven Clay Consultants, Inc.
The Charlotte and Gary Ernst Fund

INDIVIDUALS

$100,000 to $1 million

Anonymous
Irénée E. Dupont, Jr.
Michael E. Gellert
Caryl and Edna Haskins
Richard E. Heckert
Kazuo Inamori
John D. Macomber

$10,000 to $99,999

Philip H. Abelson
L. Thomas and Margaret G. Aldrich
American Cancer Society
Anonymous
Dr. and Mrs. David Baltimore
Bruce W. Ferguson
Lois Severini and Enrique Foster Gittes
Mr. and Mrs. Robert G. Goelet
David Greenewalt
Pembroke J. Hart
Robert and Margaret Hazen
William R. Hearst III
Richard A. and Martha R. Meserve
Paul F. Miller, Jr.
William and Nancy Turner
George W. Wetherill

$1,000 to $9,999

Anonymous
Bennett Archambault
Donald D. and Linda W. Brown
William Compston
John F. Crawford
Howard C. and Eleanora K. Dalton
Edward E. David, Jr.
James and Alma Ebert
Jo Ann Eder
Andrew Fire
Richard E. and Frances G. Hein
Kyoichi Ishizaka
Paul N. Kokulis
Gerald D. Laubach
Marlow V. Marrs
Chester B. and Barbara C. Martin, Jr.
Alvin E. and Honey W. Nashman
Evelyn Stefansson Nef
Eugenia A. and Robert C. Seamans, Jr.
Dan and Maxine Singer
Allan Spradling
David F. Swensen
W. John R. and Mendelle Tourover Woodley
Charles Yanofsky

Under $1,000

Jagannadham Akella
Paul A. Armond, Jr.
Toshi Asada
Horace W. Babcock
Manuel N. Bass
Bradley F. and Virginia W. Bennett
Dr. and Mrs. Paul Berg
Walter G. and Shirley A. Berl
Giuseppe and L. Elizabeth Bertani
Montgomery S. and Joanne Bradley
Dorah and A. Stanley Brager
Walter C. and Jeanette S. Brown
Gordon Burley
Donald M. Burt
Alice and Peter Buseck
Robert Cadmus
Dana Carroll
James F. Case
Britton Chance
King-Chuen Chow
Robin Ciardullo
John and Annette Coleman
John R. and Muriel H. Cronin
Babette S. Dalsheimer
Peter and Sarah Davis
Igor B.and Keiko Ozato Dawid
Vincent De Feo
John P. de Neufville
John and Ruth Doak
Bruce R. Doe
Dr. L.A. Drake
Donald and Brenda Elthon
Sandra and Andrew Faber
Dorothy Ruth Fischer
Marilyn L. Fogel
Laurence W. Fredrick
Barry Ganapol
Susanne E. Garvey
Alberto Giesecke
M. Charles Gilbert
Walter A. Good
Helen M. Habermann
Stanley R. Hart
Dr. William K. Hart
H. Lawrence Helfer
Margot W. Heller
Alfred D. Hershey
Satoshi Hoshina
Haifan Lin and Edna I. Hu
Dr. Emilie Jaeger
Mrs. Kamitsuki
Mac L. Keith
Mark E. and Peggy A. Kidwell
Joan and Joe Klein
David C. Koo
Olavi Kouvo
Ikuo Kushiro
Otto C. and Ruth Landman
Arthur and Faith W. LaVelle
Harold Lee
Steven and Nancy L'Hernault
Alan and Caroline Linde
Charles A. and Elizabeth Little
Felix J. Lockman
Robert H. and Dorothy A. McCallister
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William Upholt and Mary Lee Morrison
Jack E. Myers
Goetz and Brigitte Oertel
Lawrence and Sheila Pakula
Jeffrey D. Palmer
Steven E. and Carol A. Pfeiffer
Rambabu Pothireddy
Alison J. Rattray
Philippe Reymond
Selwyn and Pamela Sacks
D'Odorcio Sandro
Marianne and Erwin Sekulow
Nobu and Kazuko Shimizu
Edwin and Virginia Shook
Dr. Erich and Lis Steiner
S. Suyehiro
K. Suyehiro
Ziro Suzuki
Georges M. and Sylvia B. Temmer
Ian Thompson
Heinz Tiedemann
George R. Tilton
Elwood O. and Doris E. Titus
Scott B. Tollefsen
Charles H. Townes
James Van Allen
Zhou Wang and Xiaoyan Cai
Evelyn M. Witkin
Kenzo Yagi
Yoshio Yaoita
Violet K. Young

U.S. GOVERNMENT

More than $1 million

U.S. National Aeronautics and Space Administration
U.S. National Institutes of Health
U.S. National Science Foundation

$100,000 to $1 million

U.S. Department of Agriculture
U.S. Department of Energy
U.S. Office of Naval Research
Space Telescope Science Institute

$10,000 to $99,999

U.S. Geological Survey
National Institute for Global Environmental Change
U.S. National Institute of Standards and Technology
Western Regional Center for the National Institute for Global Environmental Change

OTHER

$10,000 to $99,999

American Cancer Society
American Committee for the Weizmann Institute of Science
Biosphere Two Center, Inc.
CRSCM-CNRS
Electric Power Research Institute
Incorporated Research Institutions for Seismology
Martek Biosciences Corporation
Texas Historical Commission

$1,000 to $9,999

The Academy of Natural Sciences
Fund for Astrophysical Research
International Human Frontier Science Program

Under $1,000

Anonymous
Mariah Associates, Inc.

THE DIRECTOR'S ESSAY: *Obtaining a Deeper Understanding of DNA*

> "THE CAPACITY TO BLUNDER SLIGHTLY IS THE REAL MARVEL OF DNA. WITHOUT THIS SPECIAL ATTRIBUTE, WE WOULD STILL BE ANAEROBIC BACTERIA AND THERE WOULD BE NO MUSIC."
>
> LEWIS THOMAS

Scientists consider a problem "easy" if it appears solvable by known methods, regardless of the scale of effort required to accomplish the task. Sequencing human genomic DNA, for example, is scientifically easy. The main obstacle is the large size of the genome, some three billion base pairs (bp), and the low throughput of individual sequencing reactions—currently 500–1,000 bp. Progress on such problems can be directly increased with larger budgets and more personnel. Presently, human genome sequencing resembles World War II–era calculating—an activity carried out by rooms of individuals with adding machines. However, like processor speeds, large-scale sequencing rates continue to increase rapidly, with no end in sight. It will not be long before machines sequence whole genomes in a day while their operators watch 3-D movies on pocket computers.

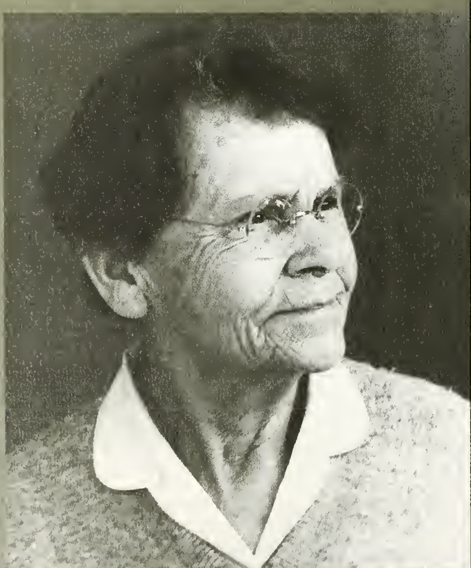
Obtaining a deeper understanding of what particular genomic sequences do throughout the many tissues and phases of an organism's life is not at all easy. Only 3% of the human sequence, the part that codes for proteins, can presently be interpreted in a meaningful way. These sequences are today largely available because of extensive studies of the protein-coding RNAs they produce. Thousands of randomly selected clones from various RNA populations have been sequenced to produce 500–1000-bp sequence "tags" called ESTs ("expressed sequence tags"). Assembling multiple tags from each gene and determining tag frequencies reveals a lot about gene structure and activity. However, even when one knows the DNA sequence of a gene, the type of protein it produces, and the cellular location and time it is expressed, it still is not possible to determine what the gene does. One needs to perturb the gene's function by making specific changes in the wild-type genome, and to assess the effects of these changes using specially tailored functional assays. Even these experiments are only a beginning and do not guarantee success. Hard problems, such as the determination of gene function, often require new ideas; adding more people doesn't always help. Instead, you need the *right* person.

Left: Extraordinarily large lampbrush chromosomes, studied by staff member Joe Gall, provide unique insight into chromosome structure and function. Looped-out areas are where DNA is actively being transcribed into RNA.

Our department exists to study hard problems. Such problems are simplified and ultimately solved by creative individuals in personal and unpredictable ways. While we cannot simply scale up to advance our work, we can create an environment that is highly conducive to our goals. One key ingredient is a mix of diversity and coherence among the faculty. We have always highly prized individuality within our department, and it remains true that each lab works primarily on a different organism. However, it has often been noted that to interact well, faculty members don't necessarily have to work on the same problem but *do* have to agree on what sort of knowledge constitutes a solution. By this definition we have a highly cohesive faculty. Moreover, there have always been common centers of interest among us. One of the highlights this year was the recognition accorded to Doug Koshland's work on eukaryotic chromosomes by his appointment as a Howard Hughes Associate Investigator. Chromosomes have long been a point of common focus within our department—both as tools for analyzing gene function and as a subject of study themselves.

Chromosome Research

DNA neither exists nor functions within cells on its own. Instead, the genome is divided into multiple segments that are each complexed with hundreds of specific proteins to make up individual chromosomes. Far from being passive information repositories, chromosomes are complex, sophisticated machines. They house the cell's machinery for storing, using, repairing, and reproducing its genetic information. All these functions are constantly responding to the position of the cell in a growth cycle, its internal physiological state, and to myriad signals received from outside. The most dramatic chromosomal changes take place when cells grow through a multi-staged process known as the cell cycle. Chromosomes accurately duplicate their component DNA during what is called the S phase. Concomitantly, they assemble new proteins to generate two tightly paired sister chromosomes and subsequently interact via specialized centromere regions with the mitotic spindle apparatus to ensure that one sister from each pair ends up in each of the two daughter cells when the cell

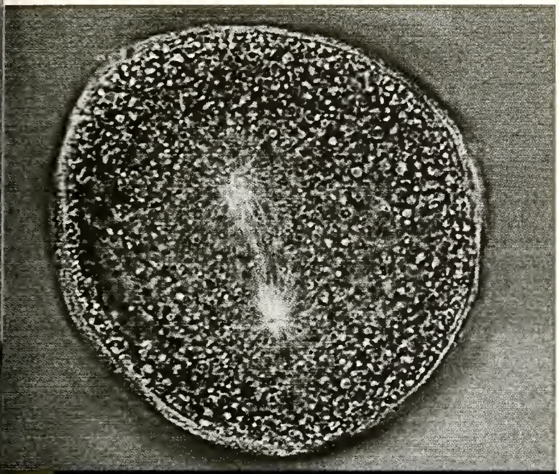


A Legend in Her Time

No discussion of chromosome research at the Carnegie Institution is complete without mention of Barbara McClintock, a Department of Genetics researcher from 1942 to 1967 and considered by many to be among this century's greatest scientists. McClintock was a chromosome researcher of unparalled skill. Using nothing but her eyes, her wits, and her microscope, she discovered decades ago that genomes were not the stable, orderly places most people envisioned, but were full of unexpected change and movement. For her famous discovery that genes could move, she was awarded a 1983 Nobel Prize.

divides at mitosis (M phase). A major difficulty in analyzing these mechanisms is the small size of most chromosomes, just a few microns long—too small for detailed resolution in the light microscope. The small size of such chromosomes is a sign of their sophistication: the DNA from a typical human chromosome, if stretched out in a line, would extend several inches. Indeed, understanding how functional DNA can be so highly condensed, and how condensation changes during the cell cycle, is itself a central problem.

Lampbrush Chromosomes

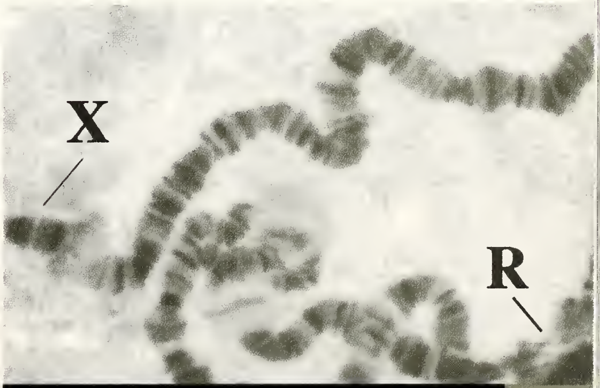


A fertilized surf clam egg *(Spisula solidissima)* undergoing its first round of mitosis. The chromosomes are being pulled to opposite ends of the cell via the mitotic spindle, as visualized with fluorescent anti-tubulin antibodies. *(Courtesy: Alejandro Sánchez Alvarado)*

Focusing on unusually large chromosomes has long provided one route around the size problem. Eggs are single cells that in some species grow to enormous size at maturity. These enlarged cells contain correspondingly large nuclei as well as large, decondensed chromosomes of unusual structure that were likened by 19th-century cytologists to the brushes used to clean lamps. Joe Gall recognized long ago the great value of these giant "lampbrush" chromosomes for analyzing chromosome structure and function. Gall's group has used lampbrush chromosomes as a starting point to identify many interesting processes that were later shown to occur in more typical chromosomes. His recent work is revealing how enzymes involved in processing RNA transcripts are packaged, stored, and transported within the nucleus and onto specific chromosomal sites (see Year Book 94, pp. 28-34). How and why oocyte chromosomes actually acquire a lampbrush appearance remains a "hard problem" of great interest to the Gall laboratory.

Chromosome Stability

Usually, chromosomes copy their component DNA faithfully when cells divide. Indeed, the apparent absence of irreversible genomic changes during the differentiation of body cells has motivated whole-animal cloning experiments such as those generating such controversy in Scotland this year. My lab has taken advantage of a different type of giant chromosome—called a polytene chromosome—to study genome stability. Polytene cells (and their chromosomes) enlarge greatly by growing without splitting into daughter cells. Each cell's nuclei acquires multiple copies of each of the cell's chromosomes, and arrays them side-by-side relatively decondensed and in precise register. However, gene-poor chromosome regions that surround the centromeres of polytene chromosomes are an exception to faithful copying. These regions instead dramatically *fail* to replicate. How and why these regions become "under-represented" was largely mysterious until recently, when postdoctoral fellow Mary Lilly discovered a mutant in which the gene-poor regions are copied along with the rest of the chromosomes.



A *Drosophila* polytene chromosome. The X chromosome is marked "X." The region rich in repetitive DNA studied by Mary Lilly and Allan Spradling is marked "R."

Normally, cells are driven into S phase and M phase by changes in the activity of specific regulatory enzymes, the cyclin-cdk kinases. In the fruit fly, one family member, cycE/cdk2, plays a key role in starting S phase, while cycA/cdk1 or cycB/cdk1 activation drives cells into M phase. Polytene cells contain cycE/cdk2 but lack the two mitotic enzymes, consistent with their ability to grow but not divide. Lilly found that in the absence of the mitotic enzymes the polytene cell cycle restarts before the DNA has finished duplicating. Thus, in normal polytene cells, cycE/cdk2 does not ensure a complete replication cycle. However, in the mutant that Lilly isolated, cycE/cdk2 persisted longer, and so replication of the gene-poor regions often finished properly. I propose that in normal polytene cells, partially replicated DNA breaks during ensuing cell cycles. The cell attempts to repair the breaks (a natural response), and in the process generates some of the distinctive properties of polytene chromosomes, including the ectopic interconnections between chromosome regions extensively studied by former Carnegie researcher B. P. Kaufmann (see Year Book 47, pp. 153-155). The new work suggests that the somatic genomes of polyploid cells are less stable than previously thought.

Chromosome Condensation

Koshland's group has taken a paradoxical approach in his chromosome studies. Rather than focus on giant cells and chromosomes, Koshland and his colleagues have coaxed new insights from an unusually small cell—budding yeast. The tiny yeast genome encodes only about 6,000 genes. Its correspondingly minuscule chromosomes are scarcely discernible by standard light microscopy. However, the great power of genetic manipulation in this organism stimulated Koshland and postdoctoral fellow Vincent Guacci to look for ways to remedy the situation. By marking specific chromosomes regions with fluorescent tags and following their location during the cell cycle, they established that the structure and behavior of yeast chromosomes bear a much closer resemblance to those of higher eukaryotes than had been supposed. They have identified mutations in which various aspects of chromosome behavior are altered, thus providing new insights into the structure and function of chromosomes in general. Their approach has been widely emulated.


Doug Koshland

Proper condensation is essential for chromosomes to fit within a nucleus and avoid knotting. By directly visualizing individual yeast chromosomes segregating between mother and bud, Koshland and his colleagues discovered that yeast chromosomes condense prior to segregation, an unexpected similarity between yeast mitotic chromosomes and those of higher organisms. Koshland's group helped identify and characterize a highly conserved new family of chromosomal proteins called SMC proteins, which are essential for proper condensation. The group proposes that a complex containing SMC proteins moves along the chromosomes and spools it into loops.

The precise separation (disjunction) of replicated chromosomes into different daughter cells relies on specialized centromere regions, which are poorly understood. With postdoctoral fellows Sasha Strunnikov (now at NIH) and Pam Meluh, Koshland confirmed that yeast centromeres behave much like their higher counterparts during cell division. The group identified two new protein components of the centromere, called Cep3p and Mif2p. Cep3p binds a specific centromere DNA element and nucleates centromere formation, while Mif2p is related to the human centromere protein CENP-C within domains that are proposed to mediate interactions with other conserved factors necessary for centromere assembly or chromosome movement. Further research has begun to reveal a specific assembly pathway of centromere components.

The maintenance of strong pairing between the two sister chromosomes is essential for proper disjunction. Rapid dissolution of this pairing is thought to regulate subsequent events during

mitosis and to ensure the proper movement of one chromosome to each daughter cell. Guacci and Koshland showed that in yeast, sister chromosomes begin to be paired as soon as they are replicated, and that pairing is not confined to the centromere but extends along the entire length of the chromosomes. By examining chromosomes directly, they identified mutants in which the sister chromosomes separate prematurely. One of these mutants, PDS1, was shown by postdoctoral fellow Orna Cohen-Fix to encode a cell-cycle regulator that inhibits chromosome separation. The product of another gene identified in the screen, Pds3p, interacts genetically and physically with one of the SMC proteins. This represents the first evidence directly linking sister chromosome cohesion and chromosome condensation.

Microtubules and Artificial Chromosomes

Yixian Zheng's and Andy Fire's groups have taken still different approaches. Zheng's lab focuses on microtubules—a key component of the mitotic apparatus. (Microtubules are the long "threads" of the mitotic spindle; they attach to the chromosomes and physically pull them apart.) Zheng and colleagues have identified a ring-shaped complex that nucleates the formation of new microtubules, and they are systematically characterizing the complex's component proteins. What they learn will undoubtedly lead to a greatly increased understanding of how chromosomes are accurately separated during mitosis.

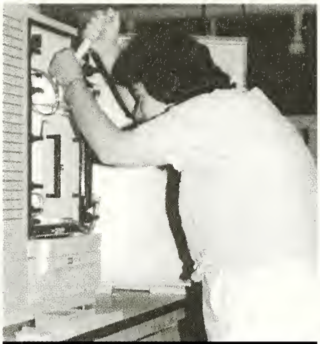
Rather than finding ways of analyzing complex natural chromosomes, Fire's lab creates artificial chromosomes within the nematode *C. elegans,* and studies their behavior. These simple chromosomes, made from multiple repeats of a gene-sized starting DNA, can persist for many generations but do not function nearly as well as regular chromosomes. Fire discovered that genes work better when surrounded by complex sequences than they do when surrounded by additional copies of themselves. His experiments illustrate the importance of chromosome organization on a large scale—yet another subject that is still very poorly understood.

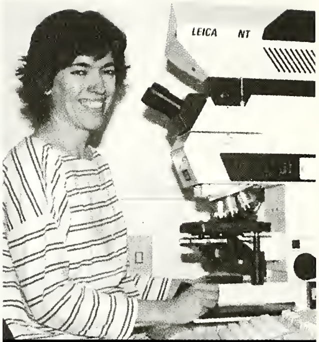
Zebrafish are prolific, fast-growing, and easily cultivated. What makes them especially attractive to developmental biologists is the transparency of their embryos, as seen in photo above. Researchers can watch tissues and cells as they develop, and chart mutations easily.

The Expansion of the Biological Enterprise

The biological sciences are changing rapidly. A continuing series of major improvements in the techniques of molecular biology, genetics, biochemistry, and cell biology are transforming our understanding and our expectations. Virtually any gene can now be cloned and sequenced, its protein expressed, purified, and analyzed both structurally and functionally, and its expression mapped within cells and tissues using sophisticated microscopic techniques. In model genetic systems (the animals and plants widely used in scientific research), nearly any gene can be mutated or mis-expressed, and its functions and interactions deduced using sophisticated genetic screens. A major by-product of research based on these techniques is the realization that virtually all multicellular organisms contain largely similar genes that function in highly conserved pathways. Increasingly, research on one organism and problem can be usefully applied to other species and problems where related genes are found to be involved. An enormous growth of the research enterprise has paralleled these advances. More than twice as many active researchers use yeast, *Drosophila,* and *C. elegans* now than they did ten years ago, while the use of newer systems such as zebrafish and *Arabidopsis* has exploded.


Marnie Halpern


Allison Pinder



Maggie de Cuevas

This department has contributed substantially to many of these changes. The rise of *C. elegans* as a system for biological research has been greatly aided by the efforts of Andy Fire. Fire developed the methods used to transform nematodes, and he produced widely used vectors for expressing genes and gene-reporter fusions. These methods and vectors have always been made freely available to the research community prior to publication and are used almost daily by every *C. elegans* researcher. The *Drosophila* community has benefited from similar technological contributions from my own group and that of former staff member Gerald Rubin. During the last few years, an estimated 25% of all the genetic stocks mailed to individuals by the National Drosophila Stock Center originated in this department. Work carried out here by Nina Fedoroff in the mid 1980s on maize transposable elements is proving to be invaluable for characterizing plant genes.

This tradition of methodological research continues, as described last year by staff associates Sue Dymecki and Pernille Rorth (see Year Book 95, pp. 77-89). This year, Marnie Halpern developed a novel method for mapping zebrafish mutations and molecular markers by generating a series of deletion-bearing haploid embryos. Her method will speed up the analysis of gene function in this powerful model vertebrate.

The new opportunities afforded by these rapid advances can only be realized by constantly updating our instrumentation. This year we were fortunate to acquire a state-of-the-art ABI377 DNA. This instrument has the capacity to generate about 25 million base pairs of sequences annually, if used to capacity. The department also obtained a new Leica confocal microscope that is quickly having a significant impact. Mapping the expression of particular genes is often an essential step in learning what genes do in developing tissues. Moreover, one of the most sensitive ways to learn what a gene does is to inactivate or mis-activate it by mutation, and then map how the expression of other genes in the organism changes. Greatly improved light microscopes have become central for these studies.

For tissues that contain multiple layers of cells, a confocal laser-scanning fluorescent microscope can obtain high-resolution information throughout the entire specimen by stimulating and recording the fluorescence signals from only a thin plane of the sample at a time. The individual sections are then recombined electronically to regenerate the correct signal. In the past, this information could only be obtained by serially sectioning the sample and examining and recording each section in turn, a tedious and often unsatisfactory process. The new instrument speeds the acquisition of information (on a prepared specimen) by at least tenfold, and achieves significantly higher resolution. Both of these instruments are now in the department as a result of support for the Spradling and Koshland laboratories from the Howard Hughes Medical Institute.

The great expansion of biological research has created unprecedented opportunities—but it has also created some significant problems. There has been a major expansion of commercial interest in biolo-

gy, so that more than half of the estimated $30 billion that will be spent this year on biomedical research will come from the pharmaceutical and biotechnology industries. One by-product is that work carried out in the department is of increasingly commercial value. We have been highly successful in licensing patents from current and former staff, and this income has helped the department renovate its facilities and achieve a higher level of activity than could have been supported by endowment and grant income alone. However, the commercialization of biological research has placed new stresses on some of the informal research traditions we greatly value. Many staff perceive that potentially useful information is now less likely to be shared by their colleagues. This trend can be discerned even in *Drosophila* research, where commercial potential was long considered laughable. I find this especially sad. The field has had an 80-year tradition of sharing information and reagents.

Fortunately, there are some forces working in favor of sharing. Competition can also spur the generation and release of information, as in the funding of a public human EST database by Merck Corp. Major sequencing labs recently adopted guidelines stressing that sequence data should be immediately submitted electronically to public databases. This approach is becoming a standard for many such publicly funded projects around the world. International agreements are needed to further encourage uniform adoption of such rules. Moreover, patent law should be updated to create more benign constraints on research sharing. If it were necessary to demonstrate significant, non-trivial uses for a gene before coverage could be claimed, the trend toward greater secrecy might be slowed.

The Contraction of Opportunities for Young Biologists

A slow decline over the last two decades in professional opportunities available to postdoctoral fellows after they complete their training continues to be a problem for the department. The high rate

Members of the Department of Embryology, September 1997: *First row (left to right):* Linda Keyes, Daniela Drummond-Barbosa, Kim Dej, Horacio Frydman, Dianne Thompson-Stewart, Mei Hsu, Orna Cohen-Fix, Allison Pinder. *Second row:* Nicole Mozden, Rejéanne Juste, Ellen Cammon, Alejandro Sánchez, Michelle Macurak, Eileen Hogan, Shannon Fisher, Melissa Pepling, Marnie Halpern, Mary Montgomery, Amy Rubinstein, Chris Murphy, Pat Cammon. *Row three:* Jia Jia Mai, Cynthia Johnson, Danny Lee, Si-qun Xu, Lisa Coles, Doug Koshland, Stacey Hachenberg. Phil Newmark, Joe Gall, Michel Bellini, Steve Farber, Brian Calvi, Jennifer Abbott, Zheng-an Wu, Debby Berry, Nick Marsh-Armstrong. *Row four:* Lisa Timmons, Ting Xie, Bob Skibbens, Allan Spradling, Patrick Kirby, Norris Bryant.

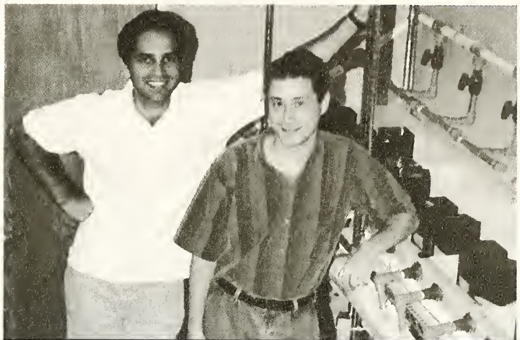
of Ph.D. production nationwide during this period has resulted in a relative shortage of attractive academic and industrial positions. One result has been the lengthening of the average time young scientists spend as postdoctoral fellows. Instead of two years, it is now common to spend four or even five years in this capacity in order to accumulate sufficient evidence of research accomplishment and future promise to obtain employment. Nationally, there are now an estimated 20,000 biomedical postdocs, many of them waiting for employment opportunities. Since these young scientists represent a major part of our department, the situation is a matter of great concern. Problems continue even after an academic job is obtained. Junior faculty members in the biological sciences now experience much greater difficulty in obtaining research grant support than they did in the past. While the young faculty in this department have all garnered significant grants, it is no longer the case that a well-prepared proposal will necessarily be successful. The upshot of the current situation is a large increase in the time and mental anguish that our faculty expend on grants and funding-related issues. An insidious by-product of these changes is that they discourage risky and truly novel research. Without the traditional support of the institution, very little work of this sort could be accomplished at the department.

Why opportunities are declining for young people, and what action should be taken, are still matters for debate. Physical scientists correctly point out that their fields began to decline sooner than ours and have not benefited from the same massive increases in commercial activity and relatively generous federal funding. Nonetheless, a few general conclusions seem clear. We need to recognize that the current system is only viable in a time of sustained growth, such as that experienced in this country between about 1950 and 1980. Not enough faculty-level positions exist at academic and research institution to sustain the current rate at which new postdoctoral scientists are produced. No solution that does not address this situation can hope to succeed.

I believe two actions could be taken on a national scale that would increase opportunities for young scientists. First, the prevalent system of faculty employment needs to be reformed. Universities have failed to replace a discriminatory system of mandatory retirement by age with a workable system of performance reviews. As a result, tenure has been converted into an entitlement to lifetime employment, thereby reducing the positions and resources available to beginning faculty. Tenure urgently needs to be replaced with a system of fixed contracts. For example, after a seven-year initial contract and a stringent review, a successful faculty member would receive a long-term contract for a fixed number of years—say 20—that could be broken only for malfeasance or departmental closure. This contract would only be renewed subsequent to a stringent outside review similar to that now used to review tenure status. All decisions on offering and renewing contracts would be based solely on future scientific promise rather than on arbitrary age. Congress should encourage adoption of such reforms.

Second, career paths outside of academic research should be regularized for Ph.D. scientists. Many opportunities now exist in the commercial sector. Opportunities for persons with a first-hand knowledge of gene-based biology can be expected to increase in other, nontraditional areas as well, because biological knowledge impinges on many aspects of our society. However, a larger and more immediate source of jobs needs to be found. I believe that teaching fulfills this requirement. Too many members of society today complete their education without ever interacting one-on-one with an experienced scientist. Persons who have engaged in research for a significant period of time understand science in a way only rarely found outside of research-oriented universities. The recruitment of Ph.D. scientists with postdoctoral experience should be encouraged by high schools, community colleges, and four-year colleges, not just universities. An increased movement of such individuals into teaching would constitute a true "educational reform" that would undoubtedly be of great benefit to society.

Yixian Zheng



Alejandro Sánchez Alvarado (left) and Phil Newmark in the planarium

News of the Department

This year the department welcomed staff member Yixian Zheng. Zheng's major interest is microtubule nucleation, a subject that impinges on the research in all our laboratories. Using sophisticated biochemical and cell biological techniques, she and members of her laboratory are opening new approaches to long-standing questions concerning cell shape, migration, differentiation, and division.

We also welcomed a new experimental organism: planaria. Extraordinary biological properties have long recommended this seemingly simple animal as a model for analyzing pattern formation and regeneration. Staff associate Alejandro Sánchez Alvarado and postdoctoral fellow Phil Newmark are advancing our understanding of these phenomena in molecular and genetic terms. They hope to develop new resources and techniques that will gain a wider audience for this fascinating model system.

Our seminar program was highlighted by the 20th Annual Minisymposium entitled "Asymmetric Cell Division." Richard Losick (Harvard University), Chris Doe (University of Illinois), Susan McConnell (Stanford), Philip Benfey (New York University), John Chant (Harvard), and Ken Kemphues (Cornell) presented one-hour talks.

Support of research in the department comes from a variety of sources besides the institution. Doug Koshland and I and various members of our labs are employees of the Howard Hughes Medical Institute. Others are grateful recipients of individual grants from the National Institutes of Health, the John Merck Fund, the G. Harold and Leila Y. Mathers Charitable Foundation, the American Cancer Society, the Jane Coffin Childs Memorial Fund, the Damon Runyon-Walter Winchell Cancer Fund, the Pew Scholars Program, the Alfred P. Sloan Foundation, the National Science Foundation, the Arnold and Mabel Beckman Foundation, and the Human Frontier Science Program. We remain indebted to the Lucille P. Markey Charitable Trust for its support.

—*Allan Spradling*

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July 1, 1996 – June 30, 1997

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[1] From 1 September 1996
[2] From 1 July 1996
[3] To 30 September 1996
[4] To 28 February 1997
[5] To 31 May 1997
[6] From 15 July 1996
[7] From 1 October 1996
[8] From 1 December 1996
[9] From 1 January 1997
[10] From 1 February 1997
[11] To 30 August 1996
[12] To 31 July 1996
[13] From 28 April 1997
[14] From 26 August 1996
[15] To 8 January 1997
[16] From 3 September 1996
[17] To 30 April 1997
[18] To 30 November 1996
[19] To 14 February 1997
[20] From 26 May 1997

Department of Embryology Bibliography

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Arabidopsis, an important player in the effort to solve the human population explosion.

THE DIRECTOR'S ESSAY:
Population Growth and Plant Biology

"THE MAIN CHALLENGE IS TO EXPAND AGRICULTURAL PRODUCTION AT A RATE EXCEEDING POPULATION GROWTH IN THE DECADES AHEAD SO AS TO PROVIDE FOOD TO THE HUNGRY NEW MOUTHS TO BE FED. THIS GOAL MUST BE ACCOMPLISHED IN THE FACE OF A FIXED OR SLOWLY GROWING BASE OF ARABLE LAND OFFERING LITTLE EXPANSION, AND IT MUST INVOLVE SIMULTANEOUS REPLACEMENT OF DESTRUCTIVE PRACTICES WITH MORE BENIGN ONES."

HENRY KENDALL[1]

In the fall of 1996, the chairman of the Carnegie board of trustees, Tom Urban, requested that each Carnegie staff member write a short essay on why his or her work is meaningful and important to the general public. He requested that responses be phrased in terms that a nonspecialist could understand, and that each of us give thought as to why expenditures on our research should take precedence over the many other socially useful things that might otherwise be accomplished with the same funds.

Many plant biologists are particularly fond of this kind of question. One of the most common motivations for choosing to pursue plant research is the direct utility of the resulting knowledge. Humans use plants for food, fuel, clothing, shelter, and production of industrial chemicals, among other things, as well as for erosion control and simple enjoyment. Fundamental knowledge about plants bears directly on one or more of these applications.

The development of genetic engineering technologies has greatly strengthened the connection between basic knowledge and practical application. Whereas in the recent past the only mechanism for plant improvement was breeding and selection within species, it is now possible to move genes that encode useful traits from one species to another. Thus, organisms which have no direct utility to humans—for example, the experimental plants of the research laboratory, such as *Arabidopsis thaliana*—have become increasingly valuable as sources of genes that can be transferred to species that are useful. Since we do not know where useful genes may be found, the "genetic appetite" of biotechnology provides an added bonus: a rationale for preserving biodiversity.

Our ability to make directed changes in plants using the tools of genetic engineering is based on deep, fundamental knowledge about the molecular mechanisms of plant growth and development. Indeed, it is likely that we will know the complete molecular structure of all the genes in *Arabidopsis* within the next four years, and we will probably know the complete structure of the rice genome a few years after that. The sequencing of these

[1] Kendall, H. W., R. Beachy, T. Eisner, F. Gould, R. Herdt, P. H. Raven, J. S. Schell, and M. S. Swaminathan (1997), *Bioengineering of Crops: Report of the World Bank Panel on Transgenic Crops.* Environmentally and Socially Sustainable Development Studies and Monograph Series 23, 30 pp. Used with permission.

Members of the Department of Plant Biology: *First row, left to right:* John Davies, John Christie, Barbara March, Stewart Gillmor, Cesar Bautista, Wolfgang Lukowitz, Rakefet Schwarz, Frank Nicholson, Chris Somerville. *Second row:* Claire Granger, Dennis Wykoff, Lori Waasbergen, Marc Nishimura, Arthur Grossman, Nadia Dolganov, Neil Hoffman, Sue Thayer, Wolf Schreible, Vittoria Canale, Julie Osborn, Patrick Eiken, Brian Welsh, Geeke Joel, Devaki Bhaya. *Third row:* Russell Malmberg, Iain Wilson, Dafna Elrad, Erika Zavaleta, Shauna Somerville, Abhaya Dandekar, Kathi Bump, Chris Lund, Eva Huala. *Fourth row:* Hans Thordal-Christenden, John Vogel, Gayathri Swaminath, Luc Adam, Sean Cutler, Michelle Nikloff, David Ehrhardt, Margaret Olney, Pedro Pulido. *Back row:* Joe Ogas, Mary Smith, Scott Kaufmann, Adam Lowry, Rudy Warren, Glenn Ford, Olle Bjorkman, Joerg Kaduk, Jim Randerson, David Kehoe, Wei Fu.

genomes will be followed rapidly by a functional analysis of the genes. Since higher plants are closely related, such detailed knowledge will be directly relevant to other higher plants. Thus, within the foreseeable future we will have a catalog of the structure and function of all the genes required actually to construct a plant—a necessary precondition in the rational improvement of important plant species.

It is probably not accidental that the development of powerful new means to improve plants coincides with a pressing need for such capabilities. One might argue that the scientific discoveries in biomedical sciences that caused the explosive growth in human population have finally worked their way through the chain of academic disciplines that link research in animal biology to basic discoveries in plant biology. Whatever the case, we are now faced with both a pressing need for new food-production technologies and a suite of new opportunities to do so.

The dimensions of the problem, and some of the opportunities afforded by the growth of basic knowledge in plant biology, have been eloquently described in a new study chaired by Henry Kendall (MIT) on behalf of the World Bank (see footnote on previous page). From this disturbing document I have abstracted the following selected passages. I strongly believe that we at the Carnegie Institution have a mandate and an obligation to consider what we might contribute toward solutions.

The world's population stands at 5.8 billion and is growing at about 1.5 percent a year. At present about 87 million people are added to the world's population each year. Population in the developing world is 4.6 billion and is expanding at 1.9 percent a year. The least developed nations, with a total population of 560 million, are growing at 2.8 percent a year. If they continue to grow at this rate, their population will double in twenty-four years. Although fertility has been declining worldwide in recent decades, it is not known when it will decline to replacement level. There is broad agreement among demographers that if current trends are maintained, the world's population will reach about 8 billion by 2020, 10 billion by 2050, and possibly 12 to 14 billion

before the end of the next century. Virtually all of the growth in coming decades will occur in the developing world.

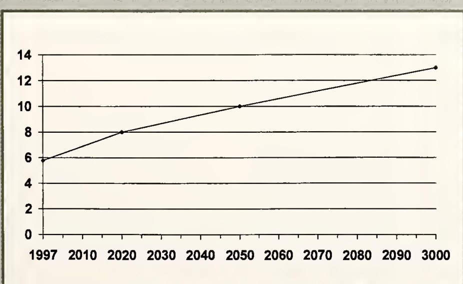
In the developing world, more than 1 billion people currently do not get enough to eat on a daily basis and live in utter poverty; about half of that number suffer from serious malnutrition. A minority of nations in the developing world are markedly improving their citizens' standard of living: in some fifteen countries 1.5 billion people have experienced rapidly rising incomes over the past twenty years. But in more than a hundred countries 1.6 billion people have experienced stagnant or falling incomes. In addition to the food shortages suffered by many in developing countries, there are widespread deficiencies in certain vitamins and minerals. To provide increased nutrition for a growing world population, it will be necessary to expand food production faster than the rate of population growth. Studies forecast a doubling in demand for food by 2025-30.

About 12 percent of the world's total land surface is used to grow crops, about 30 percent is forest or woodland, and 26 percent is pasture or meadow. The remainder, about one-third, is used for other human purposes or is unusable because of climate or topography. In 1961 the amount of cultivated land supporting food production was 0.44 hectares per capita. Today it is about 0.26 hectares per capita, and based on population projections, it will be in the vicinity of 0.15 hectares per capita by 2050.

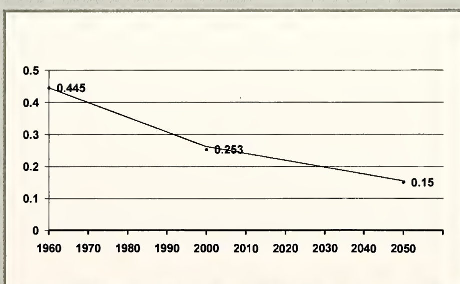
Urbanization frequently involves the loss of prime agricultural land, because cities are usually founded near such land. Losses of prime land are often not counterbalanced by the opening of other lands to production because the infrastructure that is generally required for market access is frequently lacking on those lands. Irrigation plays an important role in global food production. Of the currently exploited arable land, about 16 percent is irrigated, producing more than one-third of the world crop.

Widespread injurious agricultural practices, in both the industrial and the developing worlds, have damaged the productivity of land, in some cases severely. These practices have led to water- and wind-induced erosion, salinization, compaction, waterlogging, overgrazing, and other problems. Since 1950, 25 percent of the world's topsoil has been lost [by erosion], and continued erosion at the present rate will result in the further irreversible loss of at least 30 percent of the global topsoil by the middle of the next century. A similar percentage may be lost to land degradation, a loss that can be made up only with the greatest difficulty through conversion of pasture and forest, themselves under pressure. In Asia, 82 percent of the potentially arable land is already under cultivation. Much of the land classed as potentially arable is not available because it is of low quality or easily damaged.

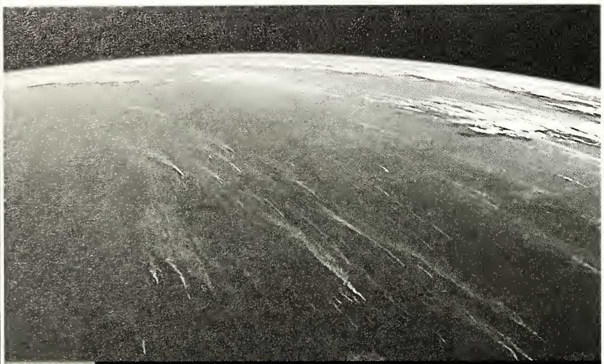
Irrigation practices contribute to salinization and other forms of land damage. For example, more than half of all irrigated land is in dry areas, and 30 percent of that land is moderately to severely degraded. There are also serious problems with supplies of water. Much irrigation depends on "fossil" underground water supplies, which are being pumped more rapidly than they are being recharged. The human race now uses



Projected World Population Growth, in billions



Land Available for Food Production, in hectares per capita



A panoramic view over South America shows smoke plumes from fires set to clear land for new planting. Increased demands for food are threatening the world's forest land.

26 percent of the total terrestrial evapotranspiration and 54 percent of the fresh water runoff that is geographically and temporally accessible.

It is now clear that agricultural production is currently unsustainable. Indeed, human activities, as they are now conducted, appear to be approaching the limits of the earth's capacity. These unsustainable activities, like all unsustainable practices, must end at some point. The end will come either from changes that establish a basis for a humane future or from partial or complete destruction of the resource base, which would bring widespread misery. It appears that over the next quarter century grave problems of food security will almost certainly affect even more people. The task of meeting world food needs to 2010 by the use of existing technology may prove difficult, not only because of the historically unprecedented increments to world population that seem inevitable during this period but also because problems of resource degradation and mismanagement are emerging. Such problems call into question the sustainability of the key technological paradigms on which much of the expansion of food production since 1960 has depended.

The main challenge for the immediate future is to expand agricultural production at a rate exceeding population growth in the decades ahead so as to provide food to the hungry new mouths to be fed. This goal must be accomplished in the face of a fixed or slowly growing base of arable land offering little expansion, and it must involve simultaneous replacement of destructive agricultural practices with more benign ones. Thus the call for agricultural sustainability. Owing to the daunting nature of this challenge, every economically, ecologically, and socially feasible improvement will have to be carefully exploited. A list of potential improvements includes:

- Conserving soil and water, with special priority given to combating erosion
- Maintaining biodiversity
- Improving pest control
- Developing new crop strains with increased yield, pest resistance, and drought tolerance
- Reducing dependency on pesticides and herbicides

The application of modern techniques of crop bioengineering could be a key factor in implementing many of these improvements. These techniques are a powerful new tool with which to supplement pathology, agronomy, plant breeding, plant physiology and other approaches that serve us now. If crop bioengineering techniques are developed and applied in a manner consistent with ecologically sound agriculture, they could decrease reliance on broad spectrum insecticides, which cause serious health and environmental problems. This reduction could be accomplished by breeding crop varieties that have specific toxicity to target pests but do not affect beneficial insects. Furthermore, bioengineering techniques could assist in the development of crop varieties that are resistant to currently uncontrollable plant diseases. At their best, bioengineering techniques are highly compatible with the goals of sustainable agriculture because they offer surgical precision in combating specific problems without disrupting other functional components of the agricultural system.

This distressing document is my general response to Tom Urban's question. I don't know of any scientific discipline that has greater potential to alleviate human misery than basic research in plant biology. In addition, I believe that plant biologists have an essential role to play in preserving biodiversity for future generations. I am heartened to see that institutions such as the World Bank are beginning to consider how the new technologies might be brought to bear on the pressing problems

associated with population growth. However, the resources of the World Bank or other major international institutions will not be effectively used unless institutions of scientific excellence in the developed world are willing to provide scientific and technical leadership. In this respect, the Department of Plant Biology can play an important role. Because of the current expertise of the staff, I believe that we will be able to make significant contributions in the general areas of biotechnology and environmental biology.

Left: A plant pathogen spore (bright dot) has landed on the surface of a barley leaf. The plant has responded by inducing the synthesis of defense compounds (which fluoresce bright yellow, and appear here as a bright glow). *Right:* Powdery mildew fungus has covered most of the surface of this *Arabidopsis* leaf.

Mechanisms of Disease Resistance

An example of a research program that has direct significance to the population problem is staff member Shauna Somerville's work on genetic mechanisms of disease resistance. It has been estimated that pests and pathogens currently destroy more than 40% of all agricultural production in Asia and Africa, and promote crop losses of approximately 30% worldwide. If mechanisms of genetic pest and pathogen resistance can be developed, these mechanisms conceivably can be put into major subsistence crops throughout the world—with no additional cost to farmers in the developing world. (Unlike the high-input agriculture of the Green Revolution, which is dependent on the use of agrichemicals, genetic pest and pathogen resistance does not impose a requirement for additional inputs; gains in productivity are thus obtained without increasing production costs.)

Shauna Somerville, staff member at the department, explores mechanisms of disease resistance in plants. Pests and pathogens promote crop losses of approximately 30% worldwide.

A highlight of Shauna's work during the past year was the mapping of 47 putative disease-resistance genes onto the genetic map of *Arabidopsis.* She and her co-workers identified the genes by carefully sifting through the database of partial cDNA sequences produced by the *Arabidopsis* genome sequencing projects. Mapping such a large number of genes was made possible by the development of physical maps of much of the *Arabidopsis* genome by colleagues in laboratories around the world. In keeping with the current trend towards the use of the internet to make data rapidly available, Shauna released the new genetic map via the internet[2] more than half a year before the corresponding research article appeared in print. The new map will facilitate the identification of genes corresponding to the many disease resistance loci in *Arabidopsis* previously identified by genetic criteria. Based on the large number of genes that have been mapped to specific locations so far, Shauna estimates that *Arabidopsis* (and other plants) contain more than 100 disease-related genes. She expects that the assignment of function to those genes in *Arabidopsis* will permit identification of the corresponding genes in crop species.

[2] http://genome-www.stanford.edu/Arabidopsis/ERT/R-EST_main.html

Biodiversity

The research programs of Chris Field, Joe Berry, and Olle Björkman address several completely different aspects of the population problem. In addition to the immediate concerns about food production, most biologists are deeply concerned about the loss of biodiversity by population pressure. Because of the increasing demand for food and fiber, it seems likely that virtually every acre of arable or semiarable land worldwide will eventually be devoted to food and fiber production, with concomitant loss of the native species. This is alarming. Once a species is lost it can never be recreated. Thus, within a few generations we will have eliminated the products of millions of years of evolution. If we understood the general principles that regulate species interdependencies in complex ecosystems, however, it might be possible to design refugia for at least some of the remaining biodiversity in threatened areas.

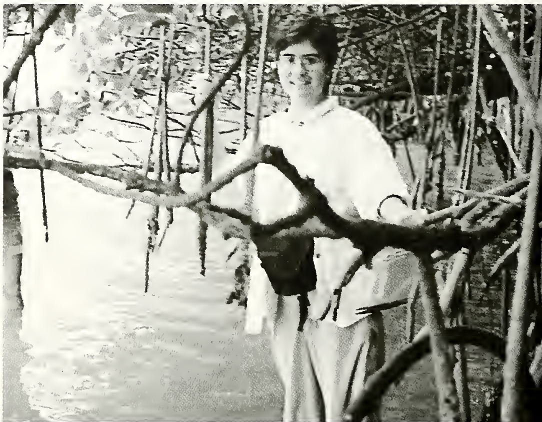

Joe Berry and Chris Field

Joe Berry recently assumed the position of scientific director of Biosphere 2, the first medium-scale facility designed to permit studies of issues associated with creation of a self-contained ecosystem. The failure to establish a stable system during the original Biosphere 2 experiment several years ago indicates the limitations to our knowledge about species interactions. Future studies at the facility should be directly relevant to the eventual creation of bio-refugia.

Similarly, Chris Field and Olle Björkman have initiated a new series of long-term studies on the role of mangrove species diversity in promoting general ecosystem diversity. As the world experiences a dramatic loss of species, many ecosystems at the same time are being fundamentally altered by the successful invasion of cosmopolitan weeds. Extinctions and biological invasions lead to progressively simpler ecosystems. How will these simplifications change ecosystem function?


Biosphere 2, previously a private human habitation experimental site, is now run by Columbia University, who plans to turn it into a national research and educational facility focusing broadly on the complex roles of the biosphere in the earth system. Joe Berry, staff member at the department, was appointed chairman of the scientific advisory committee last year.

A central issue in global change, the ecological role of diversity is also a fundamental issue in ecology. To date, experimental studies on the role of biodiversity in ecosystem function have examined artificial ecosystems with manipulated biodiversity. Though revealing, these experiments address only a fraction of the possible functions of biodiversity. They provide little access to features of biodiversity that become important only over very long periods of time or across broad ranges of environmental variables.

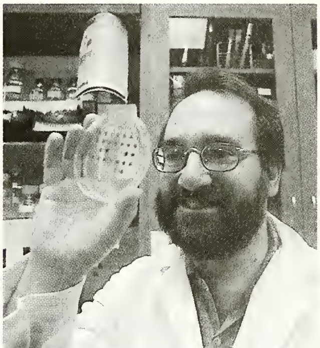

On Viti Levu, the largest of the Fiji Islands, Stanford graduate student Laura Hoffman pauses in her work. With Olle Björkman, Chris Field, and collaborators, Hoffman is investigating mangrove ecosystems in the South Pacific.

To extend the range of ecosystem studies, Chris, Olle, and collaborators are using funding from the A.W. Mellon Foundation to investigate mangrove (coastal woody) ecosystems in the South Pacific. These ecosystems exhibit a spectacular biodiversity gradient, with as many as 30 mangrove species spread across Australia, New Guinea, and the Maylasian Peninsula. Progressively fewer species are found as one travels eastward. This diversity gradient is a result of biogeographic factors. All of the species can almost certainly survive in all of the sites, but some disperse poorly and others disappear through the balance of local extinction and recolonization.

The gradient of mangrove species diversity is also a natural experiment, conveniently poised for addressing the biodiversity/function relationship. Chris, Olle, and co-workers are just beginning to do measurements on these ecosystems, as they develop techniques for exploring biomass, net primary production, nutrient balance, resistance to and recovery from disturbance, and ecological factors like habitat for other species. Ultimately, studies such as this one will make it easier to decide how much we as a society should invest in protecting biodiversity, and to determine the likely success of the outcome.

Algal Blooms

The ecological problems associated with population pressure are not restricted to terrestrial habitats or even higher plants. Eutrophication processes caused by anthropogenic influences, such as dumping of incompletely treated sewage or runoff from heavily fertilized agricultural land, have many harmful effects on aquatic ecosystems. Among the most undesirable are increasing dominance of cyanobacteria in the phytoplankton community structure and the "blooms" of microalgae that appear periodically. Toxic strains of algae are becoming a common mark of such blooms, but no one understands why. While environmental factors that favor cyanobacterial growth are known, the appearance of toxic strains remains a mystery. Some of the toxins (eg., neurotoxins, hepatotoxins) are more than 100 times more toxic than potassium cyanide. Their influx into the urban distribution web of drinking water are reported with increasing frequency and pose a serious problem for public health. Because symptoms can be confused with those of other infective diseases transmitted by water, the cause is not always quickly identified. In rural areas, the deaths of cattle, domestic animals, birds, and other wild animals coincide with dense toxic blooms. These are not isolated and occasional cases, but a growing problem, apparently caused by increased numbers of eutrophized water bodies. The ultimate control of algal blooms will probably require improvements in watershed management. Knowledge of algal and cyanobacterial responses to various environmental conditions might also contribute to the solution. Such studies can be helpful, for example, in determining which nutrients are critical to the spread of algal blooms.


Art Grossman

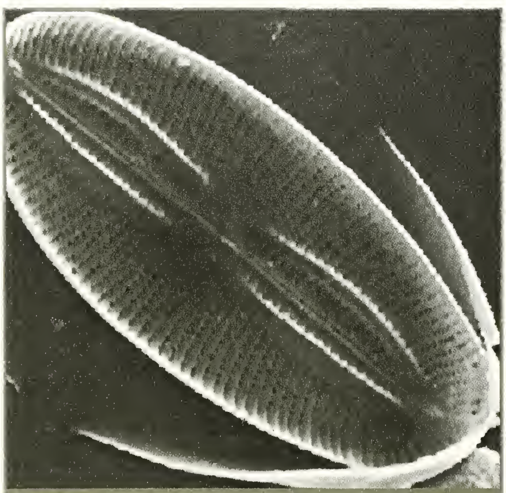
A major portion of the capital expenditures in the department this year has been allocated to the construction of new instruments that will permit the steady-state cultivation of a number of independent cultures of algae and cyanobacteria under a wide variety of growth conditions. Art Grossman intends to use these facilities to extend his studies on the acclimation of algae to variations in light and nutrient availability. His laboratory has recently isolated what appears to be the first polypeptide from an algae that can sense changes in the nutrient status of its environment. A major direction will be to identify other proteins involved in the acclimation to nutrient limitation of the cyanobacteria *Chlamydomonas reinhardtii*, and to define clearly the roles of these proteins in the acclimation process.

An analogous project with cyanobacteria in the Grossman lab has resulted in the isolation of several mutants of the cyanobacteria *Synechococcus* that are abnormal in their responses to nutrient limitation. In one of these mutants (strain PCC7942), Grossman and co-workers have identified a

regulator that is critical for survival during both sulfur and nitrogen limitation. By developing an understanding of how photosynthetic organisms acclimate to nutrient and light availability, it may be posible to enhance our ability to extend the range of environments in which plants and algae can flourish, thereby increasing our ability to efficiently harvest photosynthetic organisms in a changing global environment.

Algae as Food Sources

There are today many opportunities for using cyanobacteria and eukaryotic algae as sources of food and even as insecticides. Algae are now being used as food supplements, as feed in aquaculture, and for assaying water quality (a number of algae are sensitive to pollutants). Some cyanobacteria have been genetically engineered to deliver insecticidal proteins to mosquito populations—a promising means of controlling outbreaks of malaria in tropical countries. Also being commercially produced from algae are specific products such as vitamin A precursors, which have antibacterial and anticancer properties, and lipid molecules containing C-25 fatty acids, thought to be important for human brain development. Diatoms (tiny, very simple algae) promise to be especially useful in the latter application. Diatoms naturally produce a high percentage of lipids with C-25 fatty acids, which are key components in fish oils. (Fish accumulate C-25 fatty acids by feeding on diatoms). Art Grossman's laboratory, collaborating with Martek Bioscience Inc., has recently developed the first method for introducing genes into diatoms. This discovery should facilitate large-scale production of C-25 fatty acids from diatoms for human consumption. Clearly, the potential of algae and cyanobacteria as valuable sources of food products and pharmaceuticals is still in its infancy.



Fallacia pygmaea, a diatom

Conclusion

The unique mandate of the Carnegie Institution provides an opportunity to direct the research at the Department of Plant Biology toward the most pressing problems of our era. Unlike academic departments at universities, we do not have an obligation to appoint faculty that represent all subjects within a discipline. Rather, we have the freedom and, I believe, the moral responsibility to focus on scientific problems associated with just one subject—the human population explosion. It is my intention during the forthcoming years to intensify the focus of the department in this direction. The recruitment of new colleagues with a personal committment to these and related problems will be one of my main goals.

— *Chris Somerville*

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July 1, 1996 – June 30, 1997

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Aida E. Wells, *Secretary*
Brian M. Welsh, *Mechanical Engineer*
Howard Whitted, *Support Engineer*[32]

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[1] From 16 February 1997
[2] From 1 May 1997
[3] From 14 July to 15 August 1996
[4] To 31 December 1996
[5] To 30 November 1996
[6] To 30 September 1996
[7] To 31 March 1997
[8] From 27 March 1997
[9] To 3 January 1997
[10] From 1 October 1996
[11] From 24 February 1997
[12] From 1 September 1996
[13] To 30 April 1997
[14] From 1 December 1996
[15] From 25 September 1996
[16] To 15 August 1996
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THE DIRECTOR'S ESSAY:

Exploring the History of Star Formation

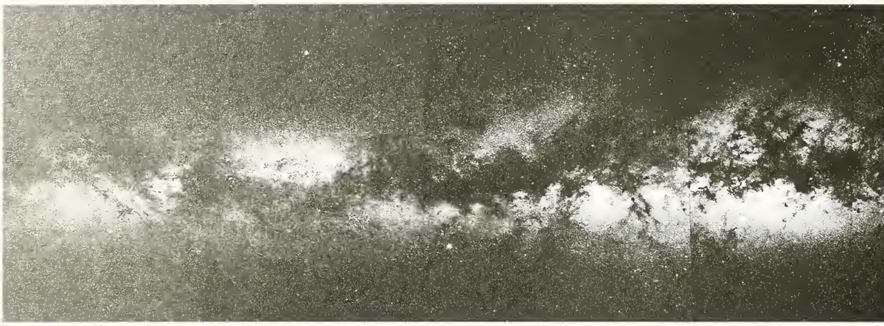
Intense star formation in NGC 6611. The new stars etch away the gas, forming pillar-like structures. The history of star formation is a major preoccupation of astronomers at the Carnegie Observatories.

Recent years have witnessed the beginnings of a notable intellectual convergence in astronomy. Even a decade ago there was a clear divide between Galactic and extragalactic astronomy, between the study of our own and other galaxies. This was due simply to what could be observed and learned in the two cases. The Galaxy is a unique object, viewed from a unique vantage point—the inside. This a sometimes useful but often inconvenient perspective. The Galaxy's global properties are hard to determine, and, in any event, are those of a single object. We can, however, obtain information on the motions, masses, ages, and chemical composition of huge numbers of individual stars within the Galaxy. This information allows us to reconstruct much of the history, particularly the very early history, of the Galaxy.

On the other hand, we *are* able to determine the global properties of a myriad of other galaxies beyond our own. However, because they are too distant for us to observe individual stars, reconstructing the histories of those galaxies has been extremely difficult. Although an accident of observational capabilities, this operational divide led to an intellectual divide, in which the things that Galactic astronomers thought about were often disconnected from those that extragalactic astronomers thought about, and much that each could have told the other often went unsaid.

This is now changing. The convergence between these views has proceeded from both ends. Larger telescopes and improved instruments have begun to allow us to carry out in neighboring galaxies the kinds of detailed studies that used to be possible only in our own Galaxy. These same improved capabilities have pushed observations of other galaxies to greater and greater distances, and thus to earlier and earlier epochs in the history of the universe. Thus, it is becoming possible to compare the early history of our own and other nearby galaxies, reconstructed star by star, with the early histories of large populations of distant galaxies.

Many things contribute to the history of a galaxy, but the dominant factor is star formation. This is



Although it is not possibl to photograph the entire Milky Way (since our vie is from the inside), it is p sible to assemble a composite mosaic. Photos at left show portions of the Galaxy from Sagittarius t Cassiopeia. Astronomers can obtain a great deal o information about the st in the Milky Way, and so are able to construct mu of its early history.

for two reasons. For one, young stars are bright stars, so that the extent of current star formation greatly influences the visible properties of a galaxy. More fundamentally, stars represent almost all of a galaxy's visible material, so the history of star formation is the history of galaxy building. The history of star formation in the universe is, in one form or another, a major preoccupation of Carnegie astronomers, and in the following few pages I will highlight some of the work undertaken in this area last year at the Observatories.

High-Redshift Galaxies

Astronomers spent several fruitless decades searching for "primeval" galaxies, those undergoing their first burst of star formation. Such galaxies were expected at very early epochs, and thus would be seen at large distances, and with large redshifts. (As a rough rule-of-thumb, objects with redshifts of a few tenths are seen as they were a few billion years ago, while objects with redshifts of 2 or 3 are seen as they were about 10 billion years ago.) However, galaxies with redshifts greater than 1 or 2 were nowhere to be found—until the last few years, when an avalanche of higher and higher redshift objects began to be discovered. Hubble Fellow Mauro Giavalisco and his collaborators Chuck Steidel and Kurt Adelberger (Caltech), Mark Dickinson (Johns Hopkins), and Max Pettini (Royal Greenwich Observatory) have been responsible for much of this progress, by applying a clever new technique to the task of discovering the occasional very high redshift galaxy among a sea of more prosaic objects on the sky. Because the universe is opaque in the far-ultraviolet region of the spectrum (owing to absorption by hydrogen), a galaxy effectively disappears when viewed at these wavelengths. Galaxies at increasingly higher redshifts drop from sight at wavelengths shifted farther and farther to the red; for those above a redshift of 3, the "dropout" wavelength shifts into the visible spectrum. Thus one can search for objects at a particular redshift by imaging a portion of the sky at two wavelengths, one below and the other above the dropout wavelength. Galaxies which appear only in the latter image are strong candidates for high-redshift objects.

Mauro Giavalisco, a Hubble Fellow at the Observatories since 1996, received his Doctorate of Research from the University of Rome, Italy, in 1992. He is a member of a team who discovered the most distant normal galaxies known.

Using this technique, Giavalisco and collaborators have assembled a sample of over 200 galaxies, most with redshifts between 2.5 and 3.5. When combined with data from other sources, their work has made it possible, for the first time, to construct an overall star-formation history of the universe, as shown in Figure 1. Star formation seems to have peaked about 10 billion years ago, and to have been in steady decline ever since. This time coin-

cides nicely with the epoch at which postdoctoral fellow Lisa Storri-Lombardi and Art Wolfe (UCSD) have found a maximum abundance of the cold gas that is the raw material of star formation.

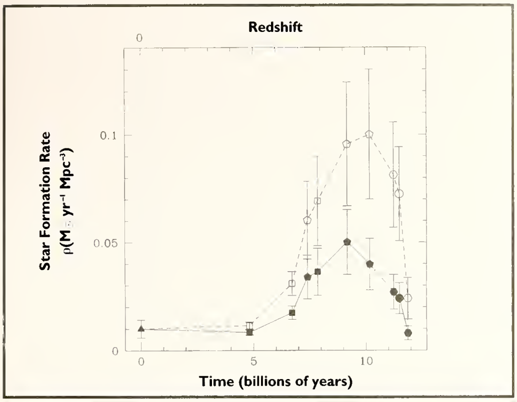
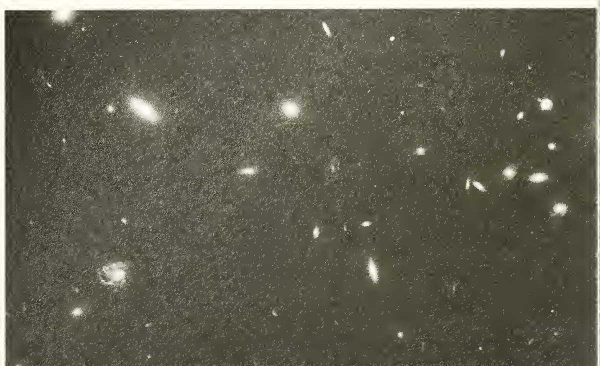


Figure 1 - The history of star formation in the universe. The horizontal axis is time, in billions of years, before the present; the vertical axis is star-formation rate. Filled points are observed rates, open points are corrected for star formation hidden within dusty galaxies. (error range is indicated by vertical bars)

Understanding galaxy formation is one of the most fundamental problems of astronomy, but it is incomplete without an understanding of galaxy evolution, i.e., how galaxies have changed between the epoch of formation and today. Much attention has been drawn to the observation, originally made by Edwin Hubble, that in regions of high galaxy density, called clusters, galaxies have less prominent disks and lower levels of star formation than do galaxies in regions of lower density. Presumably then, the environment of galaxies affects either how they form or how they evolve. The latter idea, i.e., that "nurture" rather than "nature" is the dominant shaper of galaxies, has motivated several decades of work by Alan Dressler and myself, comparing galaxies in high- and low-redshift clusters. The early days were tough-going. When observed from the ground, high-redshift galaxies are faint smudges which reveal little of their nature. However, with the Hubble Space Telescope the smudges become observable objects, allowing us to examine distant galaxies in the same detail as nearby ones.

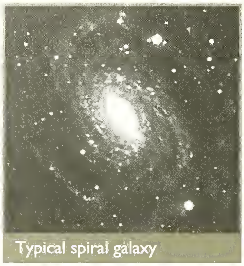
During the past year, Dressler and I, and our collaborators, Richard Ellis, Amy Barger and Bianca Poggianti (Cambridge), Ian Smail and Ray Sharples (Durham), Harvey Butcher (Leiden), and Warrick Couch (Univ. New South Wales), have been analyzing images from HST and spectra obtained from ground-based telescopes of a large set of clusters at redshifts of about 0.5, seen as they were about 5 billion years ago. These data have confirmed the conclusions we drew from earlier HST data that galaxies in higher-redshift clusters tend to have less-regular structures, exhibit more signs of disturbances, and more often undergo brief bursts of star formation than those in clusters at lower redshift. These peculiarities may be only the consequences of youth; such galaxies are midway between the violent epoch of formation and the well-settled maturity of nearby galaxies. Alternatively, such disturbances may be the signs of processes at work which have driven galaxy evolution in these environments. The new observations cast some doubt on one attractive process: violent mergers between pairs of disk galaxies which result in one spheroidal

Alan Dressler



A section of the distant cluster of galaxies CL0939+4713. In contrast to nearby clusters, the galaxies populating this region have an abundance of young stars. Many exhibit signs of disturbance, possibly caused by interactions with their surroundings. *(Courtesy: Alan Dressler and NASA)*


Typical spheroid galaxy


Typical spiral galaxy

remnant. Galaxies whose spectra suggest strong past disturbances are mostly disk galaxies, not spheroidals, suggesting that whatever perturbs the galaxies does not remove their disks. Also, the ratio of disk to spheroidal galaxies seems to have been the same 5 billion years ago as it is today. Only the fraction of disks with active star formation has declined, suggesting a more gentle process at work, which removes the gas out of which stars are born without disrupting the basic structure of the galaxy.

Extragalactic Background Light

One grand measure of the sum total of all the stars in the universe is the extragalactic background light, or EBL. The EBL is the total light shining on Earth from all the galaxies in the sky—a very simple quantity, but one which has been maddeningly difficult to measure. It is easy to see individual galaxies, or at least their bright centers, but the contribution of things too faint to be seen is a crucial portion of the EBL, and very hard to quantify. The light of galaxies is overwhelmed by the glow of the atmosphere, by the zodiacal light (sunlight scattered off dust in the solar system), and by the diffuse Galactic light (starlight scattered off dust in the Galaxy). Any determination of the EBL must first remove, with great accuracy, all of these much larger light sources. Many attempts have been made over the years, but all have failed.

Now, predoctoral fellow Rebecca Bernstein, working with Wendy Freedman, has finally succeeded in detecting and measuring the EBL. She has removed atmospheric glow by observing from space with HST. She determined and subtracted the contribution of zodiacal light by measuring the strength of spectral features due to sunlight, and she handled diffuse Galactic light by carefully modeling the distribution of dust and starlight in the Galaxy, and picking a region of the sky where these are minimal. The result is gratifying: she finds that the strength of the EBL is very close to what one would expect from counts of galaxies on the sky, *if* one makes two significant corrections. One must include light from the faint outer parts of galaxies, light that is normally missed when the brightness of galaxies is measured, and one must include all of the very-low-surface-brightness galaxies that hide below the glow of the night sky. One of the most significant implications of Bernstein's work is that these two corrections *are* sufficient—there is no large source of light in the universe beyond what we can see or conservatively infer. Thus, almost all of the star formation in the universe has, apparently, occurred in rather ordinary galaxies.

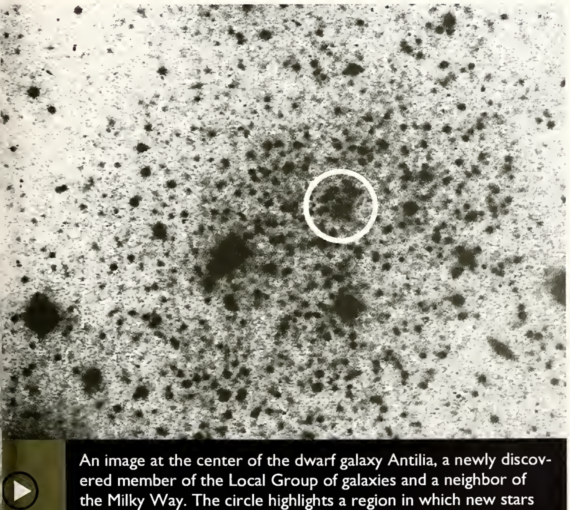
The nature and number of such very-low-surface-brightness galaxies has been a preoccupation of several Carnegie astronomers, including Bernstein and DTM Carnegie fellow Stacy McGaugh. Observatories Hubble Fellow Julianne Dalcanton described her work on these objects in Carnegie Year Book 95 (pp. 31-36). This year she has finished her survey, and concludes that low-surface-brightness galaxies provide one-third of the luminosity density of the universe, an amount very consistent with Bernstein's results. Dalcanton and her collaborators David Spergel (Princeton) and Frank Summers (Hayden Planetarium/Columbia) have developed a simple theory for the formation of high- and low-surface-brightness disk galaxies, which allows one to understand the latter as being low-mass objects with an exceptionally large amount of rotational energy.

Dwarf Galaxies of the Local Group

The history of star formation in other galaxies of the Local Group—the nearest neighbors to the Galaxy—is beginning to be explored in some of the detail previously available only in the Galaxy. Most of these galaxies are dwarfs: dwarf irregulars, which are small disk galaxies with large star-formation rates, and dwarf spheroidals, which are

diskless objects with little or no present star formation. The history of dwarf galaxies is of particular relevance to galaxy evolution, for these galaxies are thought to be objects with the most unusual histories of star formation. Dwarf irregulars might be "young" galaxies, most of whose stars formed quite recently, while dwarf spheroidals are suspected to be "dead" dwarf irregulars, in which star formation has somehow been snuffed out.

Postdoctoral fellow Carme Gallart and her collaborators Antonio Aparicio (currently visiting from the IAC, La Palma), Gianpaolo Bertelli (Rome), and Cesare Chiosi (Padua) have been combining observations of the brighter stars in a set of Local Group dwarfs with models of the dwarfs' stellar populations. Contrary to expectations, they find that the present star-formation rates in the dwarf irregulars NGC6822, Pegasus, LGS-3, and Antlia are no higher than star-formation rates were in the past. On the other hand, a study of the dwarf spheroidal galaxy Leo I shows that it contains more intermediate age and fewer very old stars than most such objects. This and other work suggests that dwarf galaxies have evolved less than often thought. It also suggests that the properties of dwarf galaxies represent a continuum, and that the traditional division of dwarf galaxies into two distinct groups, dwarf irregulars and dwarf spheroidals, may need much revision.



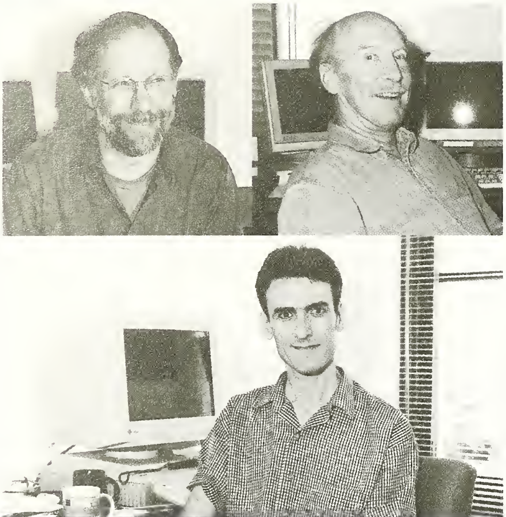
An image at the center of the dwarf galaxy Antilia, a newly discovered member of the Local Group of galaxies and a neighbor of the Milky Way. The circle highlights a region in which new stars are currently being formed. (LCO 100", March 1997)

The Chemical History of the Galaxy

The heavy elements—which astronomers loosely call "metals"—are all products of the life cycles of stars; the gas in the Galaxy has been enriched in metals by all the prior generations of stars. Thus, a star's pattern of metal abundances is a powerful tracer of the history of star formation prior to that star's birth. By studying the elemental abundances in the most metal-poor stars, one may probe the earliest stages of the formation of our Galaxy.

George Preston, Andy McWilliam, Ian Thompson, and Steve Shectman have begun a new survey, using the du Pont Reimaging Camera, to find a large sample of stars with metal abundances as low as 10^{-5} that of the sun. Such stars, if they exist, would have abundances an order of magnitude lower than those seen in the most metal-poor stars currently known, most of which were discovered in the previous Carnegie survey, completed in 1995.

Meanwhile, McWilliam has been analyzing spectra of 43 of the most metal-poor stars found in the previous survey. The pattern of elemental abundances in these stars suggests that the gas from which they formed was enriched by the heavy elements produced by only a very small number of dying stars (as few as one). Since those stars are known to have had very short lifetimes (typically less than 10^8 years), one must suppose that the observed metal-poor stars formed very shortly after the first generation of stars. How long ago that occurred is suggested by the abundance analysis of another star, CS22892-052. Using the decay of the radioactive isotope ^{232}Th in this star as a chronometer, McWilliam and collaborators estimate that the oldest stars formed in the Galaxy 15±4 billion years ago. This time is consistent with the age of the universe derived from the Hubble Constant, whether one uses the lower value obtained by Allan Sandage and his collaborators, or the somewhat higher value obtained by Wendy Freedman and her collaborators.



Stephen Shectman *(top left)* and George Preston *(top right)* have been searching for the elusive "population III" stars since the late 1970s. These stars, believed to be the oldest stars in our Galaxy and perhaps the universe itself, have never been detected. Joining them in a recent survey are staff members Ian Thompson and Andrew McWilliam. McWilliam *(above)* is a world leader in the study of the Galaxy's early chemical history. He joined the staff last year.

People

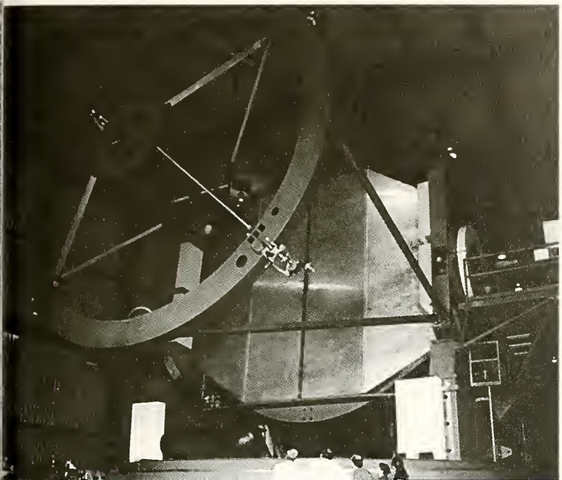
The tragic death of long-time staff member Jerry Kristian in mid-1996 left a large void. After a truly exhaustive search, the best possible replacement was found just down the hall: Andrew McWilliam was appointed as our newest staff member on July 1, 1997. Dr. McWilliam received his Ph.D. in 1988 from the University of Texas, and has been at the Observatories since 1991. He has served as a research associate and as a senior research associate, and was the Observatories' first Barbara McClintock Fellow. He is a world leader in the study of the early chemical history of the Galaxy, and continues the Observatories' long and distinguished history in that field.

The same search turned up another exceptional young astronomer, Dr. Luis Ho. A 1995 graduate of Berkeley, and currently a postdoc at the Harvard/Smithsonian Center for Astrophysics, Dr. Ho has been active in many areas of extragalactic astronomy but is best known for his work on very weak active galactic nuclei. He has accepted appointment as staff associate, beginning in the summer of 1998.

Renovations of the Hunt Building

Having completed construction of the new shop/laboratory building and the new lecture hall, and renovation of the west wing, we began work this year on the renovation of the Hunt Building. This is the Observatories' original headquarters building and the last survivor of 80 years of California earthquakes. It is of architectural significance to Pasadena, and of historical significance to the Carnegie Institution and indeed to all of astronomy. From the sub-basement, which still contains the ruling engines on which John Anderson and Harold and Horace Babcock produced most of the early diffraction gratings used in the world's observatories, to the attic, which holds the leavings of generations of departed astronomers, the Hunt Building is imbued with the history of 20th-century astronomy. Our intent has been to tread lightly in these spaces, repairing decay and upgrading the building's mechanicals, while returning the appearance of the building, as much as possible, to the elegant simplicity it possessed in the 1910s. Simultaneous with the remodeling work, which is under the direction of Alan Dressler, Pat McCarthy has been supervising the renovation and reorganization of the library, which is the physical and intellectual heart of the building and of the Observatories. The work on the Hunt Building and library has been made possible by generous grants from the Fletcher Jones, Ahmanson, and Ralph M. Parsons Foundations, and by a bequest from the late Alexander Pogo, longtime Observatories librarian.

Magellan I enclosure and auxiliary building on Mount Manqui, Las Campanas, photographed in January 1997.



Magellan I mirror mount, assembled at L&F Industries. It was disassembled and shipped to Chile in late 1997.

The Magellan Project

The Magellan Project made rapid progress during this period. The year started with the Magellan I telescope enclosure beginning to rise above its foundation on Manqui Peak, and with the first subassemblies of the mount taking shape at L&F Industries in Los Angeles. The year ended with a nearly-complete enclosure and a mount undergoing final tests before disassembly and shipment to Chile. Also at L&F, final work was being done on the primary mirror cell, before shipment to Tucson where the mirror support system will be installed.

Polishing of the primary mirror finally began at the Steward Observatory Mirror Lab in Tucson. After a considerable wait, during which figuring was completed on the new primary for the MMT telescope, the Magellan primary was moved to the polishing table and all work finished on the back of the mirror. As the year ended, the Magellan mirror was again off the polishing table for a few months while finishing touches were applied to the MMT mirror. Satisfactory progress continues on the polishing, at Contraves, of the f/11 secondary. Unfortunately, progress has been slower with the f/15 secondary, a very lightweight silicon carbide honeycomb being manufactured by the Vavilov State Optical Institute in St. Petersburg. Silicon carbide is a very difficult material, and a satisfactory mirror blank has not yet been produced. The polishing of the tertiary mirror is nearing completion at Kodak.

At year's end, the first steps were taken in construction of the second Magellan telescope. A contract was signed with the Steward Observatory Mirror Lab for the production of the primary mirror and mirror support system. Meanwhile, the formal Magellan Consortium Agreement, between Carnegie, Arizona, Harvard, MIT, and Michigan, made its halting way forward, running the gauntlet of astronomers and lawyers and deans. Impatient of a formal tying of the knot, the consortium's astronomers began discussions on the challenging issue of coordinating instrument development between the institutions.

In the spring of 1997, Peter de Jonge stepped down after four years as Magellan Project manager. He will continue to play a large role in the construction of both Magellan telescopes, but the position of project manager has been assumed by Matt Johns, who has been Magellan Project systems engineer. The Magellan Project has produced remarkable results with an exceptionally small staff, in large part because of the talent, energy, and dedication of Peter de Jonge, Matt Johns, and Steve Shectman, the Magellan Project scientist. A new addition to the project staff this year is Charlie Hull, who has taken up the position of lead mechanical engineer. He replaces Frank Perez, who has moved to Chile to take charge of local operations.

Instrumentation

The Observatories have a long and illustrious history of instrument development, stretching back to the days of Hale and Ritchey. However, the Magellan telescopes represent an unprecedented challenge for Carnegie instrument builders. The size and complexity of Magellan instruments greatly exceed that of anything built here before. Moreover, an entire complement of instruments is needed all at once, at the beginning of operations, if the power of the new telescopes is to be exploit-

Magellan working group, *left to right:* David Carr, Greg Bedthauer, Steve Shectman, Matt Johns, Charlie Hull. *Not pictured:* Joe Asa.

ed. Happily, the challenge is not financial. Thanks to the generous support of the Observatories' friends, particularly Carnegie trustee Kazuo Inamori, the funds are available to build what we need. The scarcer resource is people. The technical staff of the Observatories was much depleted during lean financial times, and has needed much rebuilding. We have been extremely fortunate during the past year to attract a very talented group of new people to work on instrumentation, including programmer Christoph Birk from Max Planck, Heidelberg, and instrumentation scientists Bruce Bigelow from Lick Observatory and Greg Burley from the University of British Columbia.

Work is progressing on three main Magellan instruments. IMACS, The Inamori Areal Camera and Spectrograph, is a uniquely powerful optical imager and spectrograph, which will produce high-quality direct images and low-dispersion spectra of objects over a field of up to 27 arc minutes. This instrument should be the workhorse of the Magellan I telescope, and a prime tool for the kinds of spectroscopic studies of faint galaxies which are fundamental to much of extragalactic astronomy and cosmology. The IMACS is being developed under the supervision of Alan Dressler and Bruce Bigelow. The very wide field of this instrument requires a very large detector array to provide coverage. Ian Thompson and Greg Burley are developing an 8192-pixel-square camera, using an array of eight 2048 x 4096 pixel CCD's. This will be one of the largest CCD cameras yet built, and is a very large challenge in itself.

The DDI Infrared Spectrograph, being built by Eric Persson and David Murphy, will be the prime infrared instrument on Magellan I. The push to greater distances and earlier epochs in the universe is a push to higher redshifts, and therefore from the optical to the infrared part of the spectrum. The DDI Spectrograph, which will have built-in low-order image correction and will be capable of multi-object spectroscopy over a field of over 3 arc minutes, will be the tool that makes such cosmological explorations possible.

The Kyocera Echelle Spectrograph, being built by Steve Shectman and Rebecca Bernstein, is intended for high-resolution spectroscopy of moderately faint objects. This elegant design is a double Littrow spectrograph, with separate red and blue sides. It is remarkably compact for a high-performance instrument on a 6.5-meter telescope. This spectrograph will be the primary tool in studies of the chemical abundances in stars, and of absorption-line QSOs.

Although most attention is going to Magellan instrumentation, the smaller Las Campanas telescopes will remain valuable and productive resources. Several instruments are under development which will provide wide-field capablilites on the du Pont telescope. The du Pont Reimaging Camera, nearing completion by Ray Weymann, provides imaging and low-resolution spectroscopy over a field of more than 25 arc minutes. A new, wider-field infrared camera, incorporating low-order active optics, is currently being built by Eric Persson and David Murphy.

—*Augustus Oemler, Jr.*

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[3] From January 30, 1997
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[13] From April 1, 1997
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THE DIRECTOR'S ESSAY:
Seismological Studies at the Carnegie Institution

"ALTHOUGH IT MAY BE DIFFICULT TO DEFINE PRECISELY THE FUNCTION OF THE INSTITUTION IN GENERAL OR AT ANY PARTICULAR MOMENT, IT IS CLEARLY THE DUTY OF THIS ORGANIZATION TO LEND ITS AID, WHEREVER POSSIBLE, TO ADVANCE FUNDAMENTAL KNOWLEDGE IN FIELDS WHICH ARE NOT NORMALLY COVERED BY THE EFFORTS OF OTHER AGENCIES, OR IN WHICH OTHER RESEARCH BODIES MAY FIND DIFFICULTY IN INITIATION OF PROJECTS . . . PROBLEMS WHICH PROMISE LARGE RETURN FOR FUTURE INVESTIGATION ARE FOUND IN THE FIELD OF SEISMOLOGY OR EARTHQUAKE STUDY . . ."

JOHN C. MERRIAM *(1921)*[1]

While seismology is presently one of the principal scientific foci of the Carnegie Institution, and research in that field is now centered institutionally within the Department of Terrestrial Magnetism, neither statement has always been true. In 1921, when John Merriam assumed the presidency of the Carnegie Institution, seismological research in the United States was not competitive with that in Japan, England, and Germany. Merriam asked Geophysical Laboratory director Arthur Day to chair an advisory committee on seismology, which recommended later that year that the Carnegie Institution initiate the development of new seismic instrumentation in cooperation with Mount Wilson Observatory and the California Institute of Technology. The committee also recommended that the institution undertake geodetic and geological studies of active fault zones in California in cooperation with the U. S. Coast and Geodetic Survey and the U. S. Geological Survey, respectively.

That same year, Merriam hired Harry Oscar Wood as a research associate in seismology. A mineralogist and geologist by training, Wood was at Berkeley at the time of the 1906 San Francisco earthquake, and his field work on that great upheaval permanently changed his research agenda. Wood began his Carnegie tenure at the Mount Wilson Observatory headquarters in Pasadena, but in 1927 he accepted an invitation by Caltech to relocate the Carnegie seismology operations to the institute's newly constructed Seismological Laboratory. Wood was both a skilled instrumentalist and a shrewd judge of talent. With Mount Wilson astrophysicist John Anderson, he developed the Wood-Anderson seismometer, a short-period horizontal instrument that became a standard at U. S. seismological observatories. Among the assistants Wood hired were Charles Richter and Hugo Benioff, each of whom went on to distinguished careers in seismology.

[1] Report of the President, *Carnegie Institution of Washington Year Book 20*, pp. 7-8, Carnegie Institution, Washington, D.C., 1921.

Left: One of the most seismically active areas on Earth, the Andes of South America have challenged DTM seismologists for decades.

During its first 10 years, the Seismological Laboratory was owned by Caltech but operated by the Carnegie Institution, and opinions differed as to the most important research directions for the lab's efforts. Wood and Day held that the problem of understanding California earthquakes was of the greatest primacy, while Caltech president Robert Millikan and Beno Gutenberg, whom Millikan brought to Caltech as a professor in 1930, were of the view that global seismology offered the greater promise for new understanding. That debate, although perhaps understandable as the natural outcome of the need of a young but growing research group to prioritize its research objectives, seems curious today, in that both earthquake mechanics and the global structure and dynamics of the Earth are now active and complementary areas of inquiry throughout the field of seismology and at both Caltech and the Carnegie Institution in particular.

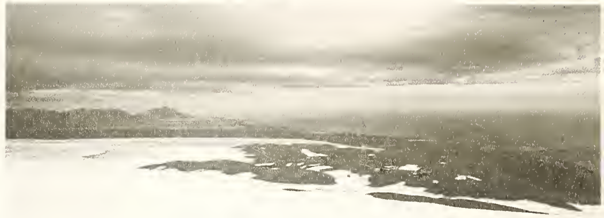
Seismic Tomography

Much of the most recent work on earth structure at DTM has exploited the power of portable broadband seismic experiments to image details of upper-mantle structure not resolvable by global networks of seismic observatories. (For a discussion of broadband seismic instruments, see Year Book 94, pp. 106-107.) One such portable experiment, led by former fellow Ingi Bjarnason (now at the Science Institute of the University of Iceland), was recently completed in Iceland. Centered on the Mid-Atlantic Ridge, Iceland is one of the world's most volcanically active hotspots. Theory more than 25 years old holds that such hotspots are the surface manifestations of upwelling plumes of hot material originating from the base of the Earth's lower mantle. Previous information, however, on seismic structure in the vicinity of hotspots, the most active of which are in oceanic areas, had not been of sufficient resolution to test the plume hypothesis.

Digging out the Santa Rosa City Hall, California, April 1906 (from *The California Earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission*)

The Carnegie Institution began setting up research departments immediately after it was founded in 1902. At the same time, it began a parallel extracurricular grants program for individual scientists. It was through this program (since discontinued) that funds were provided for Carnegie's first undertaking in seismology—the publication of the classic book *The California Earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission,* by Andrew C. Lawson, Chairman. This book, a detailed record of the 1906 earthquake that devastated San Francisco and much of the surrounding area, is number 87 in the institution's monograph series. It remains in print and in demand.

Given a sufficient experiment duration, a portable seismic network records a number of distant earthquakes from a variety of directions; differences in arrival times of compressional and shear waves can then be inverted to recover the three-dimensional seismic velocity structure beneath the network. This technique, known as seismic tomography, was applied with spectacular success to data from the Iceland network collected between 1993 and 1996 by a group led by Cecily Wolfe, a former Harry Oscar Wood Fellow at DTM and now on the scientific staff at the Woods Hole Oceanographic Institution (WHOI). The tomographic images depict a low-velocity anomaly having the shape of a vertical cylinder beneath central Iceland; the cylinder has a radius of about 150 km and extends vertically from less than 100 to more than 400 km depth (Figure 1). The low velocities indicate temperatures that are higher than normal by about 200-300°C. The seismic anomaly thus confirms that there is a plume-shaped zone of upwelling extending at least to 400 km depth, the greatest depth resolvable from tomography for a network no wider than the land area of Iceland. The inferred thermal anomaly is in line with estimates made by others from the much greater rate of formation of new crust at Iceland than along other sections of the Mid-Atlantic Ridge.



Top: The Vatnajökull glacier at its southern perimeter. The south coast of Iceland can be seen in the distance. (Photo taken in 1995 by former fellow Ingi Bjarnason.) *Left:* Bjarnason, now at the University of Iceland, is shown installing a portable broadband seismic instrument in Iceland. Data from an array of these instruments produced the first high-resolution seismic image ever obtained of an active mantle plume, shown below left.

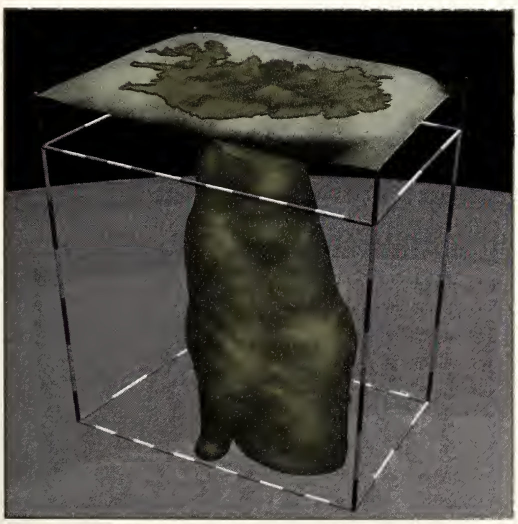


Figure 1 - Perspective view of the upper-mantle shear-wave velocity anomaly beneath the Iceland hotspot imaged by seismic tomography. The anomaly depicted, the contour for shear velocity 3% less than normal, outlines a cylindrical zone of hot upwelling material extending from more than 400 km depth to the uppermost mantle. The gray scale on the bar grid changes every degree of latitude and longitude and every 100 km in depth.

An independent type of seismic observation made with the portable network in Iceland pushes the evidence for an upwelling plume to more than 700 km depth. At the two primary seismic discontinuities marking the top and bottom of the upper-mantle transition zone, normally at about 410 and 660 km depth, upward-traveling compressional waves convert part of their energy to shear waves. These two discontinuities are thought to arise from pressure- and temperature-sensitive mineralogical phase transitions, but while a greater temperature increases the pressure (and thus the depth) of the transition for the shallower phase change, a temperature increase drives the 660-km transition to lower pressures. Thus regions of the mantle that are hotter than normal between 400 and 700 km depth should have a thinner than normal transition zone. A group led by former postdoctoral associate Yang Shen, now at WHOI, has mapped the thickness of the transition zone beneath Iceland from the differences in arrival times of P-to-S wave conversions at the 660-km and 410-km discontinuities. They found that the transition zone is 20-25 km thinner than normal beneath central Iceland but of normal thickness elsewhere (Figure 2, next page). The center and width of the anomalously thin, and thus hotter than normal, transition zone coincide with the center and width of the seismic velocity anomaly imaged tomographically at 100-400 km

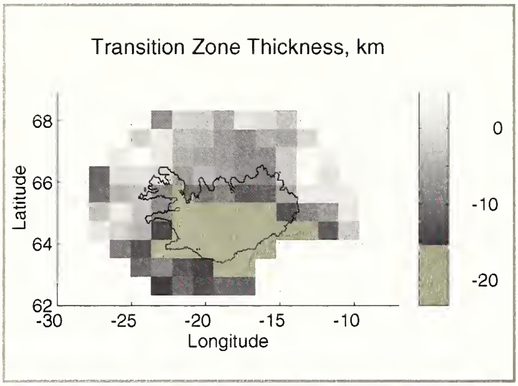


Figure 2 - Map view of variations in the thickness of the mantle transition zone (the depth interval between the 410-km and 660-km seismic discontinuities) beneath Iceland, relative to the thickness in a standard earth model. The 20-25 km thinner transition zone beneath central Iceland indicates higher-than-normal temperatures across a region 300-400 km in diameter, consistent with upwelling of a hot plume from the lower mantle.

depth. The Iceland experiment has thus provided the first seismic confirmation that plumes originate in the lower mantle, as theory had predicted.

A very different type of structural target for upper-mantle tomography was enabled by the overlapping duration of two portable seismic experiments at a common latitude in South America. One experiment, carried out by David James and collaborators from the Universidade de São Paulo, was in the ancient continental interior of Brazil. The second, conducted by Paul Silver and coworkers from the University of Arizona, was in the Bolivian and northern Chilean Andes (see Year Book 94, pp. 109-115). Inversion of the travel times collected by both networks, as well as by nearby permanent stations, was carried out by John VanDecar, another former Wood Fellow now at *Nature* magazine, and his colleagues at DTM and collaborating institutions. As a result, the upper-mantle structure across the entire South American continent has been imaged with unprecedented spatial resolution (Figure 3). The eastward-dipping, high-velocity anomaly at the western margin of the continent traces the subduction of the Nazca plate beneath South America well into the lower mantle. High velocities extending to at least 300 km depth at the eastern end of the profile correspond to the lithospheric roots of the São Francisco craton, the most ancient continental segment in the region of the experiments. (For a discussion of the formation and stability of ancient continental cratons, see Year Book 93, pp. 109-117.)

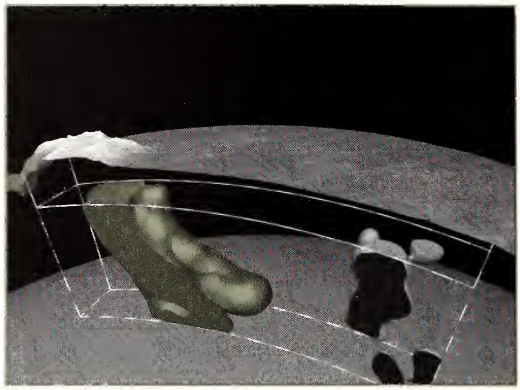


Figure 3 - Perspective view of upper-mantle compressional-wave velocity beneath South America at about latitude 20 S. The high-velocity anomaly at left (gold contour, 0.65% greater than normal P-wave velocity) is a seismic image of the eastward subduction of the oceanic Nazca plate beneath western South America. The low-velocity image at right (gray contour, 0.65% less than normal P-wave velocity) may be a relic of the hot mantle plume that fed volcanic eruptions in Brazil more than 80 million years ago. The gray scale on the bar grid changes every degree of latitude and longitude and every 100 km in depth.

The feature in Figure 3 least anticipated at the start of the seismic experiments is the low-velocity anomaly that extends vertically from about 200 km to at least 500 km depth in the eastern portion of the image. In map view, this anomaly is approximately circular in cross section; in three dimensions its shape is similar to that of the Iceland plume. Directly above the anomaly is the Paraná basin, the site of huge flood-basalt eruptions about 130 million years ago and alkalic volcanism 80 to 90 million years ago. The intriguing question is why such an anomaly should be present so long after the end

Servicing a seismic station at El Tuito, Mexico, former Wood Fellow John VanDecar *(far right)* poses with Universidad Autónoma de México students. Data from an array of portable seismometers in Mexico are being used to study the subduction of the young and relatively hot lithosphere of the offshore Rivera plate

of magmatism and presumed mantle upwelling. The answer suggested by VanDecar and coauthors is a combination of mantle temperatures that remain higher than normal and a distinct mantle composition that has stabilized the hot material against further ascending flow. Whatever its origin, the anomaly has sufficient vertical extent to suggest that the thickness of mantle material moving westward with the South American crust must be many hundreds of kilometers, much greater than the generally accepted thickness of the tectonic plates. This inference is fueling new ideas for the nature of mantle dynamics in the Atlantic and for the more general question of the nature of the forces driving plate motions.

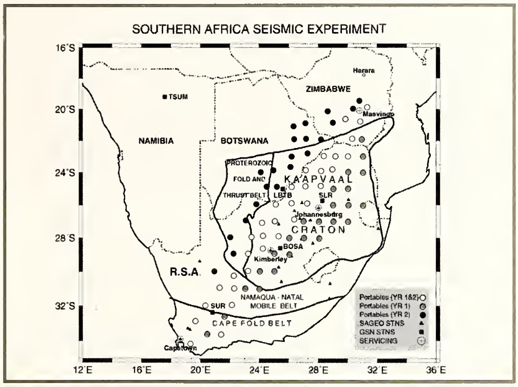


Figure 4 - Location of the southern Africa seismic experiment with respect to political and schematic geological boundaries. Circles denote sites of portable stations, squares are sites of permanent broadband Global Seismic Network stations, and triangles are digital vertical-component stations of the South African Geological Survey. The long axis of the network is aligned to optimize observations of earthquakes in Asia, the South Atlantic, and South America.

An even more ambitious portable seismic experiment aimed at elucidating the deep structure of an ancient continent is now underway in southern Africa (Figure 4). The experiment, led by David James and Paul Silver and their colleagues from the Massachusetts Institute of Technology and several universities and mining companies from the Republic of South Africa, Botswana, and Zimbabwe, involves 56 broadband stations operating at nearly 80 sites over a two-year period. Compressional and shear wave arrival times will be inverted to determine the three-dimensional structure of the crust and upper mantle beneath the network, which has an aperture of 2000 km in its long-axis direction. This high-resolution structure will provide critical contextual information for a variety of geochemical and petrological studies now being carried out by Richard Carlson and Steven Shirey of DTM, Joe Boyd of the Geophysical Laboratory, and their colleagues at collaborating institutions. That work includes characterization of xenoliths from the many kimberlite pipes in the region, as well as geochronological and geological documentation of the major magmatic and deformational events that have marked the 3.6 billion years of preserved history of southern Africa. The overarching goal of the interdisciplinary project is a significantly improved understanding of the processes that led to the formation and stabilization of ancient continental cratons.

Setting up a solar-powered portable seismometer—one of an array of 56 instruments in southern Africa—are Dave James *(center)*, current Wood Fellow Suzan van der Lee *(right)*, and Jane Gore, a graduate student at the University of Zimbabwe. Map at left shows installation sites.

Strain Transients

Much of the ongoing work at DTM on the mechanics of earthquakes can be broadly regarded as the study of strain transients, i.e., temporal variations in rates of deformation within plate boundary zones and their relationship to earthquakes and plate motions. Strain transients can be classified into four groups. Coseismic strain accompanies fault rupture during an earthquake. Postseismic strain transients, which arise from slow fault slip following an earthquake and from the diffusion of stress surrounding a zone of earthquake rupture, have been well documented, although a full characterization of governing mechanisms and time scales remains incomplete. Strain transients that precede and perhaps even trigger earthquakes constitute a

most interesting third category. If such transients are common and can be recognized, their importance for earthquake warning is manifest. Finally, there are strain transients not evidently associated with earthquakes, or at least earthquakes comparable in size to the strains involved.

Following the 1989 Loma Prieta and 1992 Landers earthquakes in California, a general appreciation among seismologists emerged that the coseismic strain accompanying large earthquakes can affect the state of stress on nearby faults and adjacent segments of the same fault, thereby increasing or decreasing the near-term probability of earthquake occurrence on those neighboring fault systems. Former Carnegie fellow Fred Pollitz, now at the University of California at Davis, and Selwyn Sacks have recently demonstrated that the long-term effects of stress diffusion following large earthquakes can have larger effects on nearby faults than the coseismic strain, but over time scales of decades rather than the few years or less over which aftershocks and fluid flow within the fault zone typically occur. A particularly strong example is provided by the devastating 1995 Kobe earthquake in Japan. This event, unanticipated on the basis of previous seismic records, occurred on a fault influenced by the postseismic strain following two great earthquakes that occurred in 1944 and 1946 along the Nankai Trough, the boundary between the Philippine and Eurasian plates offshore of central Honshu. Models for that postseismic strain by Pollitz and Sacks (Figure 5) indicate that the conditions favoring seismic slip on the fault that eventually ruptured during the Kobe earthquake steadily increased in the half century following the great Nankai Trough events.

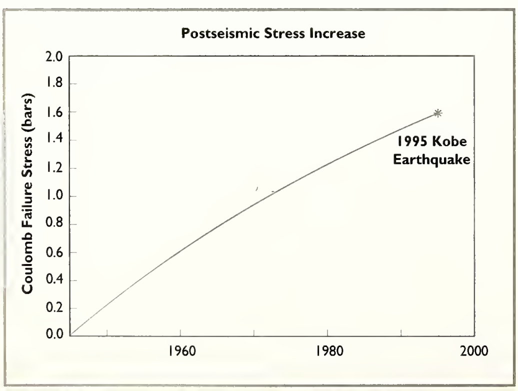


Figure 5 - On the basis models of postseismic deformation in central Honshu, Japan, following the great earthquakes of 1944 and 1946 along the Nankai Trough, normal stress on northeast-southwest-trending faults in the vicinity of the city of Kobe became progressively less compressive during the ensuing 50 years. The predicted Coulomb failure stress on the Nojima fault, the fault that eventually ruptured during the 1995 Kobe earthquake, indicates that the fault became increasingly prone to failure during that same interval.

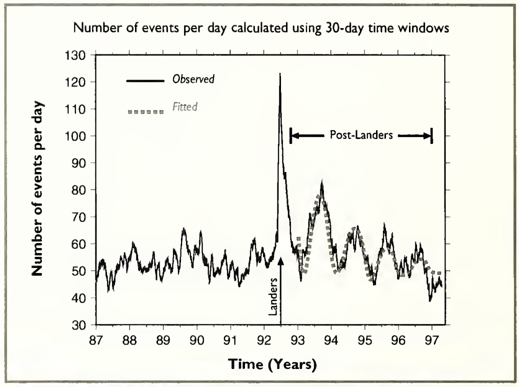


Figure 6 - Seismicity in the western United States following the 1992 Landers earthquake (arrow) displays an annual periodicity not seen prior to the earthquake. The model fit to the data (dashed line) is a decaying sine wave, with a best-fitting decay constant of about 1.5 years.

Another type of coseismic and perhaps postseismic strain associated with the Landers earthquake has recently been discovered by postdoctoral associate Shangxing Gao and Paul Silver. The 1992 Landers earthquake was unusual in that seismic waves from that event apparently triggered seismicity at a number of sites hundreds of kilometers distant from the epicenter. What Gao and Silver have documented is that the enhanced seismicity stimulated by the Landers event has an annual cycle, but one for which the cycle peaks are slowly decaying to normal levels (Figure 6). Their interpretation is that the annual periodicity is driven by variations in barometric pressure, a hypothesis that leads to the surprising inference that stress perturbations as small as a few tens of millibars are capable of affecting seismic activity. If their hypothesis is correct, then the triggering of seismicity in 1992 may have been at least partly the result of coseismic changes in the local static stress field. The decay in the amplitude of the annual seismicity cycle, Gao and Silver suggest, may reflect postseismic diffusion of those coseismic stresses.

Borehole strain instruments, such as those developed by Selwyn Sacks and colleagues, because of their good sensitivity at periods of months and less, provide unique information on strain transients of

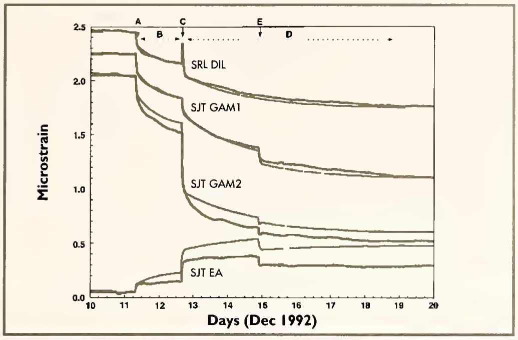


Figure 7 - Strain data (bold lines) from a slow earthquake on the San Andreas fault in California. Station SRL is a Sacks-Evertson strainmeter sensitive to changes in volume (dilatation) and located less than 1 km west of the fault. Station SJT is a tensor strainmeter located about 2 km west of the fault; the strain components plotted are shear strain (GAM1 and GAM2) and horizontal areal strain (EA). The slow earthquake was complex, consisting of at least five subevents, labeled A through E. A model for the fault slip during this event (thin lines) indicates that the fault offset and area affected are equivalent to a magnitude 4.8 normal earthquake.

all types. Such instruments recently yielded particularly clear evidence to Alan Linde and colleagues for a type of strain transient known as a slow earthquake, a discrete slip event along a fault that occurs so slowly that either no seismic waves are generated or any accompanying earthquakes are much smaller than would be expected for the amount of slip and area of fault involved. Strainmeter records from the slow earthquake, which occurred in December 1992 along the San Andreas fault in California, are shown in Figure 7. There are two remarkable aspects of these records. First is the complexity of the week-long event, comparable to that displayed by the temporal patterns of fault rupture during large earthquakes. Second, the slow earthquake occurred along a segment of the fault system that also experiences normal earthquakes of similar equivalent magnitude. Slow earthquakes are thought to be common along some plate boundary fault zones, notably in oceanic regions, and they may accommodate a significant fraction of the relative plate motions along such boundaries. Many more events of the type shown in Figure 7 must be observed and characterized, however, before the relationship between slow and normal earthquakes and their underlying distinguishing mechanical processes can be understood.

Merriam's prescient view that seismology was a field ripe for discovery remains valid more than three quarters of a century later. While the Wood-Anderson seismometer has been supplanted by a new generation of broadband seismometers and strainmeters, we are still discovering first-order features of the earth's internal structure and we have yet to solve what Wood termed "the earthquake problem." Through the continued investment in novel instrumentation, a careful selection of creative experiments, and a willingness to await and then exploit new types of observations, Carnegie staff, fellows, and associates can expect to continue to reap the large scientific returns yet promised by seismology.

— Sean C. Solomon

DTM staff on the front steps of the main building, Broad Branch Road campus, December 1997. *First row (left to right):* Sean Solomon, Janice Dunlap, Vera Rubin, George Wetherill, Ben Pandit, Adriana Kuehnel, Fouad Tera, Rosa Maria Esparza, Suzan van der Lee. *Second row:* Lawrence Patrick, Nelson McWhorter, François Schweizer, Mary Horan, Georg Bartels, Richard Carlson, Sandy Keiser, Shaun Hardy, Mary Coder, John Almquist, Paul Tomascak, Pablo Esparza. *Third row:* Michael Seemann, Merri Wolf, Michael Acierno, Jianhua Wang, David Weinrib, Terry Stahl, John Graham, Steven Shirey, Patrick McGovern, Alan Linde, Kenneth Chick, Emilie Hooft, Daniela Power, Stephen Kortenkamp, Roy Scalco, Michael Regan. *Last row:* Erik Hauri, Conel Alexander, Larry Nittler, Randy Kuehnel, Alan Boss, L. Thomas Aldrich, David James, Harri Vanhala, and Georg Rümpker.

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June 30, 1996 – July 1, 1997

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[19] From May 1, 1997
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[24] To June 12, 1997

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THE DIRECTOR'S ESSAY:
Understanding the Earth at High Pressure

"THE GENERAL PURPOSE OF THE GEOPHYSICAL LABORATORY IS TO LEARN AS MUCH AS POSSIBLE CONCERNING THE COMPOSITION AND NATURE OF THE EARTH AS A WHOLE AND TO UNDERSTAND THE PROCESSES BY WHICH, DURING GEOLOGIC AGES, IT REACHED ITS PRESENT STATE."

LEASON H. ADAMS[1]

I am often asked at social occasions, "What does the Geophysical Laboratory do?" Sometimes I answer that we study the interiors of the Earth and other planets. Usually the questioner nods his or her head and goes over to the bar for another drink. However, if I say that we use gem-quality diamonds to squeeze different kinds of materials to learn what happens at very high pressures, and are even interested in making diamonds in the laboratory, there is a more enthusiastic response. Often, an interesting discussion will follow.

The difference in response to these two explanations of our work is, in fact, an accurate reflection of new and exciting shifts in geoscience research. Our ever-increasing abilities to manipulate, simulate, and synthesize materials in the laboratory hold the key for understanding, if not always solving, the major problems in geoscience and planetary science today.

Many important advances result from the synthesis and characterization of materials. In condensed matter physics and chemistry, three of the most promising areas of research over the past decade have their roots in semi-accidental syntheses of materials: high-temperature superconductors, quasicrystals (materials exhibiting an unusual five-fold symmetry), and fullerenes (or buckyballs). Although similar, and in some cases identical, materials had been made previously by man or nature, it was the ability to ***characterize*** these materials, using advanced instrumentation, that made these discoveries such exciting leaps forward. The superconductor and fullerene discoveries, for example, attracted Nobel prizes.

The Geophysical Laboratory is recognized throughout the world as a leader in the application of fundamental physics, chemistry, and biology to problems in the earth sciences. In its early years, few other laboratories of its kind existed. Today, there are many, compelling the department's scientists to focus more critically on the most promising and innovative research directions. The Laboratory's

[1] Annual Report of the Director of the Geophysical Laboratory, 1945-1946, *Carnegie Institution of Washington Year Book 45*, Carnegie Institution, Washington, D.C., 1946

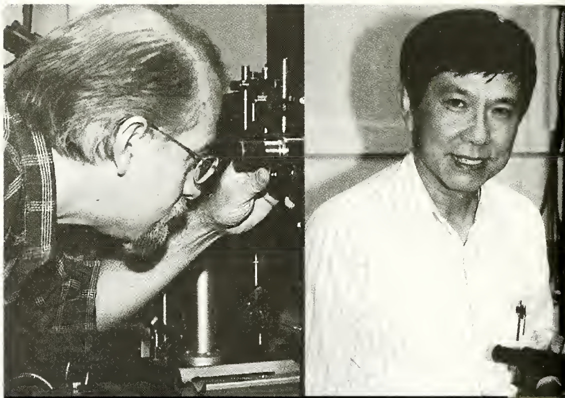
efforts are unified under the rubric of condensed matter geophysics. Condensed matter geophysics emphasizes the study and synthesis of new and existing materials—including biomaterials, liquids, glasses, and crystalline solids—that can lead to discoveries in such diverse areas as volcanology, planetary interiors, superhard materials, and prehistoric climates, as well as to fundamental understanding of the physics, chemistry, or even biology found at high pressure.

Progress is founded on a combination of original ideas and new instrument capabilities. It is more true now than ever that innovative research depends on the development, acquisition, and upgrading of instruments. And as instruments become more and more capable, they become more sophisticated. Over the past several years, the Geophysical Laboratory has made a special effort to acquire and upgrade its instrumentation in order to be competitive in the areas of research of most interest to our staff.

Center for High Pressure Research

A highly significant component of our research activities takes place as part of the Center for High Pressure Research (CHiPR), one of 14 centers (in different scientific fields) established in 1991 through funding by the National Science Foundation Science and Technology Center Program. Principal academic components of CHiPR are the State University of New York at Stony Brook, the Carnegie Institution, and the University of California at Davis. Funds supplied by NSF, the three institutions, and external grants are used to support a variety of initiatives related to high-pressure research.

The principal goal of CHiPR is to study fundamental questions about the evolution, structure, and dynamic state of Earth and other planets. Carnegie participants generate new information about material properties at high pressures and temperatures, and synthesize new materials of interest to physics, chemistry, materials science, and the earth sciences. Experimental work is complemented by theoretical computer simulations. CHiPR also fosters the development of new instrumentation and techniques, especially those related to the diamond-anvil cell and the multi-anvil experimental apparatus.



Russell Hemley *(left)* and Dave Mao *(right)*, two of CHiPR's principal investigators at the Laboratory.

The multi-anvil apparatus is used for synthesizing large volumes of material, such as silicate perovskite, $(Mg,Fe)SiO_3$, thought to be a major phase in Earth's lower mantle; new hydrous magnesium silicates; and iron sulfides, thought to be present in the core of Mars. Often, there is enough material left over to be used in other kinds of experiments. The apparatus consists of three split-cylinder cubic anvil presses that are used for experiments at pressures up to 20-30 GPa and temperatures to 2000-2500°C. Its design, construction, and operation is the result of an intriguing interaction among our own scientific and support staff, small companies in Maryland and New York, and scientific ideas from a number of different institutions in the U.S. and abroad.

Diamond-anvil cells employ two brilliant-cut diamonds (from 1/8 to 1/3 carat in size) pressed together with a mechanical device. The diamonds,

Some of the CHiPR staff at the Geophysical Laboratory *(from left)*: Jinfu Shu, David Mao, Chang-Sheng Zha, Thomas Schindelbeck, Alexandre Goncharov, Ren Lu, Russell Hemley, Sean Shieh.

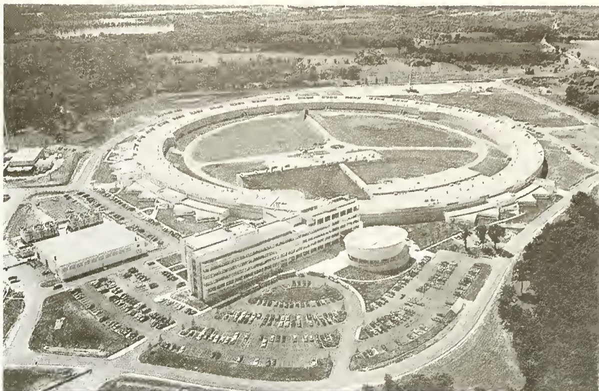
in turn, compress a polycrystalline or single-crystal sample. In addition to its extreme hardness and compressive strength, diamond is unique in permitting pressures up to and beyond 360 GPa—the pressure at the center of the Earth—while at the same time allowing a variety of physical measurements to be made.

Unfortunately, many of the natural diamonds used in most high-pressure experiments contain mechanical flaws and inclusions of other atoms, such as nitrogen. The flawed diamonds break before the sample being studied reaches very high pressures. Those that contain inclusions create a fluorescence that interferes with the light emitted by the sample in spectroscopic experiments. Collaborating with the General Electric Company, we are currently testing synthetic G.E. diamonds for strength and fluorescence. The results thus far are very promising, and show spectroscopic details not observed previously with natural diamonds.

Synthetic diamonds. The strength and clarity of these stones make them ideal for high-pressure experiments.

Before CHiPR was founded, the United States was not competitive on an international scale in many aspects of high-pressure research. Now, because of CHiPR's advances and the consequent incentive for other American research groups, we are doing very well. CHiPR is in its seventh year of funding from NSF and will continue for at least four additional years. NSF has announced that there will be a new competition for Science and Technology Centers that will require a new proposal in 1998 in order to avoid a lapse in funding when the current grant terminates. We intend to submit a new proposal whose theme will be distinctly different from the previous one, but that will build on experience gained in the intervening period.

Synchrotron Radiation

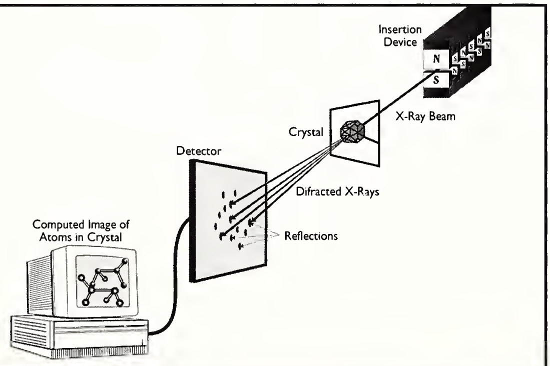


Argonne National Laboratory's Advanced Photon Source, an x-ray synchrotron source covering 80 acres, produces the nation's brightest beams for research.

For the past several years, some of the most exciting research on materials has been conducted at national synchrotron facilities, both in this country and abroad. Geophysical Laboratory scientists, led by David Mao, Russell Hemley, Yingwei Fei, Larry Finger, George Cody, and myself, are involved in the design, construction, and operation of experimental beamlines at two different U. S. synchrotron radiation facilities—the National Synchrotron Light Source at Brookhaven National Laboratory (NSLS) and the Advanced Photon Source (APS) at Argonne National Laboratory. We also conduct experiments at the Cornell High Energy Synchrotron Source (CHESS), and at the European Synchrotron Radiation Facility (ESRF). The APS and ESRF are "third-generation" synchrotron-light-source facilities, dedicated to the production of extremely brilliant x-ray beams for research. The advantages of these x-ray beams over those in older machines is that they allow scientists to study smaller samples, more-complex systems, and faster reactions and processes, and to gather data at a greater rate and level of detail. At the APS, a beam of positrons (positively charged electrons) are accelerated in a linear accelerator to 200 MeV and beamed on a tungsten wafer, creating electron-positron

pairs. The positrons are separated magnetically and accelerated further to 450 MeV. They are collected in an accumulator ring and injected into a booster synchrotron, where their energy is raised to 7 GeV. They are then injected into the 1104-meter storage ring, where they orbit and generate x-rays when passing between bending, undulator, or wiggler magnets.

"First light" was produced at APS in March 1995. Geophysical Laboratory staff, in collaboration with colleagues participating in the Consortium for Advanced Radiation Sources at the University of Chicago, have been performing experiments there since early 1997. Synchrotron usage is similar to the use of telescopes by astronomers in that the researchers must travel to remote locations and make measurements of photons with extremely sensitive detectors.



How the APS works. The beam from the insertion device, steered by magnets, strikes the crystal sample, diffracting the x-rays and producing an image on the detector. Computer software then produces an image of the atomic structure of the crystal.

Because of the availability of synchrotron facilities and advances in high-pressure instrumentation, the study of materials at ultrahigh pressures is currently experiencing an unprecedented surge of breakthroughs deemed inconceivable only a few years ago. As megabar experimentation becomes freed from previous technical limitations, a wide range of new scientific problems in physics, chemistry, materials science, and planetary sciences can be addressed. Many of these advances were originally developed by Geophysical Laboratory scientists at the NSLS, which is the only synchrotron source in the world housing two rings under the same roof. One ring provides high-brightness infrared (IR) radiation, while the other provides high-energy x-radiation. We are implementing state-of-the-art IR and x-ray facilities at the two rings for diamond-cell applications.

In ultrahigh-pressure research, the power of an integrated approach is far greater than the sum of individual techniques. Comprehensive understanding of high-pressure phenomena relies on a combination of complementary measurements. Because fundamental alterations in bonding and interatomic interactions are induced by extreme pressure and temperature conditions, these phenomena are mutually related. It is most desirable, and often essential, to study the same sample at the same pressure and temperature with various spectroscopic and diffraction techniques. Above one megabar, diamond anvils break when the pressure is released. To perform a separate experiment for each type of measurement not only multiplies the cost and time, but also introduces severe uncertainties in data correlation. The integrated study eliminates the common controversy of comparing separate studies with different samples at different times and conditions.

We plan to add key equipment at NSLS to create a comprehensive, integrated center for high-pressure experiments. This will involve integration of a diamond-cell operation and sample preparation laboratory, a laser-heating laboratory, a Raman/fluorescence/optical system, and a Brillouin spectroscopy laboratory. We are also building at NSLS the only synchrotron infrared beam line in the world devoted to studies of condensed matter geophysics. Each one of these techniques is capable of probing a multitude of valuable material properties. For example, comprehensive geochemical studies of vibrational and electronic properties of minerals require both Raman and IR data that follow different selection rules. The combination of synchrotron x-ray diffraction and Brillouin spectroscopy yields complete geophysical information comparable to seismic observations of the Earth's interior.

We expect that this new approach will replace the usual fragmented mode of synchrotron experimentation, in which users preload their diamond cells at home prior to traveling to perform a single synchrotron experiment at an assigned beam line, will evolve into an integrated environment where users can conduct interactively and efficiently a complete experi-

ment from sample preparation and cell alignment to an array of synchrotron and spectroscopic studies. We anticipate that the NSLS center will become an international resource for users in the high-pressure field, and will be used to address major problems in experimental geophysics and geochemistry of planetary deep interiors.

Theoretical Mineral Physics

Throughout its first 80 or so years of existence, the Geophysical Laboratory concentrated on experimental approaches to scientific problems. However, it became apparent that theoreticians were beginning to develop computational approaches to explore properties of and processes in crystals and molecules. Theoreticians use only fundamental quantum physics in their calculations (first-principles calculations) to help understand experimental observations, to guide the selection of new experimental studies, and to make predictions outside the currently accessible or studied regime. Ronald Cohen joined the Laboratory in 1990 to develop such a research program and, in 1995, he obtained a grant from the NSF Academic Research Infrastructure Program to purchase a departmental supercomputer, an 8-processor (recently upgraded to a 12-processor) Cray J916/8-1024.

Ronald Cohen

This machine has allowed Cohen and his colleagues to pursue computational problems that would otherwise have been impossible. However, even when using the machine at maximum capacity, there are limits to the size of problems that can be addressed; requirements of state-of-the-art first-principles computations remain immense. Cohen plans to upgrade the machine to provide 15-25 times more processing power than is available now. Although much faster supercomputers with large-scale parallel architectures exist, these machines are shared among many institutions, and an individual share is much smaller than what the planned upgrade will give the Laboratory and its collaborators. The new system will be unique internationally as a state-of-the-art supercomputer dedicated to mineral physics and geochemistry. Key problems to be studied include phase diagrams, equations of state, elasticity and anelasticity of important mantle and core phases and melts, and the energetics, nuclear magnetic resonance spectra, and dynamics of natural organic systems and organometallics.

The First Billion Years

In early 1997, I began thinking about a theme that encompasses much of the research being conducted at the Geophysical Laboratory and the Department of Terrestrial Magnetism. It occurred to me that there are many mutual areas of interest in studies involving the physical, organic, and biological processes that took place during the first billion years of Earth's history, as well as related events occurring before and after this period. Recent applications of theory, modeling, and experimentation have shown that we can learn much about what was going on during the first billion years, even though there is little direct geological evidence from that period. (Table below shows some of the most important events.)

Table of Events Occurring during the First Billion Years*

Years Before	Time from Year	Event
4,566,000,000	0	Early condensation of refractory material
4,565,000,000	1,000,000	Formation of planetesimals
4,555,000,000	11,000,000	Igneous activity in planetesimals
4,500,000,000	66,000,000	Moon formed
4,450,000,000	116,000,000	Core segregation, atmospheric outgassing
4,430,000,000	136,000,000	Final accretion of Earth
3,800,000,000	766,000,000	Oldest known rocks - earliest life???
3,500,000,000	1,066,000,000	Oldest known fossils

*From Allègre, Manhès, and Göpel (1995)

I discussed the concept of organizing discussion and research around the theme "The First Billion Years" with Maxine Singer, who helped organize a meeting at the Carnegie Building in downtown Washington, D.C. on June 23. The meeting was attended by several people from the Laboratory and DTM, as well as by Allan Spradling and Joe Gall from the Department of Embryology, Greg Ferry from Penn State, Claude Klee from NIH, Singer, and myself. The discussions were lively and informative, and the participants expressed the desire to inaugurate a formal collaborative program through specific research projects, symposia, and outreach to the scientific community and possibly even the general public.

New ideas, new instrumentation, and greatly increased computing power have allowed investigators to develop viable theories and models about how the Earth formed and evolved during its early history. Individuals in the respective, co-located departments are already working on or thinking about relevant topics. These include the role of supernovae, condensation of the solar nebula, accretion of planetesimals, formation of a magma ocean and processes therein, formation of continents, giant impacts, core separation, evolution of the ocean and atmospheres, the chemical and physical processes that could have led to first life, and the subsequent roles of bacteria and other microorganisms. Especially promising is a study exploring how these various events were linked to each other. We are in a unique position to exploit recent discoveries in these fields and to develop a coherent theme for joint research that could itself benefit enormously from the current interest in the origin of life on Earth and on other planets. A collaborative research program based on the many different aspects of Earth history in the first billion years might attract enthusiastic support from both federal agencies and private foundations. This is clearly one of the most interesting areas for research that I can imagine and one that can be addressed immediately without large initial investments in equipment and personnel time. I believe that the theme has great potential for a number of new initiatives, including:

- Developing new research directions
- Pursuing common research goals that could

Members of the Geophysical Laboratory: *First row, left to right:* Ed Hare, Rus Hemley, George Cody, Doug Rumble, Marilyn Fogel, Joe Boyd, Hat Yoder, Charles Prewitt, Ron Cohen, Yingwei Fei, Bjorn Mysen, Neal Irvine, John Frantz, and Dave Virgo. *Second row:* Roy Scalco, Margie Imlay, Sean Shieh, Uwe Wiechert, Pedro Roa, Sue Schmidt, Virginie Pinel, Yoshi Iizuka, (unidentified person), Paul Meeder, Kei Hirose, David George, Mark Wah, Lawrence Patrick, Dan Frost, Jinfu Shu, Alex Goncharov, Nabil Boctor, Jen Blank, Madury Sommayazulu, and Hexiong Yang. *Third row:* John Straub, Steve Coley, Gotthard Sághi-Szabó, Carol Lynch, Joel Ita, Wei Li, Qilian Cui, Ren Lu, Yanzhang Ma, James Farquhar, Bobbie Brown, Chang-Sheng Zha, Jay Brandes, Glenn Goodfriend, Connie Bertka, Richard Ash, Lars Stixrude, and Mark Teece. *Missing from picture:* Andy Antoszyk, David Bell, Alison Brooks, Pan Conrad, Paula Davidson, Chris Hadidiacos, Tahar Hammouda, Jingzhu Hu, Boris Kiefer, Julie Kokis, David Mao, Charlie Meade, Bill Minarik, Thomas Schindelbeck, Gerd Steinle-Neumann, Viktor Struzhkin, David Teter, and David Von Endt.

result in increased collaboration among Carnegie departments and with other institutions
- Providing increased credibility and basis for seeking financial support from private foundations as well as federal agencies
- Capitalizing on current interest in origin of life and life on other planets
- Establishing theme for local seminar series
- Organizing major conference(s)
- Organizing major publication(s)

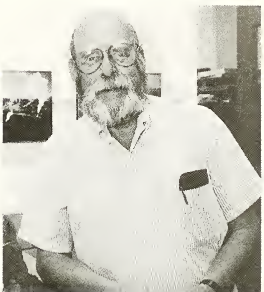
Hydrothermal Vents and the Origin of Life

A prime example of the type of research program such an effort might produce is already under way at the Laboratory, led by Robert Hazen. A couple of years ago, Hazen began to think about the general problem of how life began, and about how organic

Hatten Yoder, Jr., (left) and Bob Hazen, participants in the Lab's new research program investigating the origin of life.

reactions thought to be essential for life might be affected by elevated pressures and temperatures. The Laboratory's extensive experience in conducting such experiments on inorganic materials led naturally to consideration of how life might have begun in the hydrothermal vents that extended into the crust below the ocean floor. It has only been 20 years since deep-sea submersibles unearthed evidence that the mineral-laden hot water surrounding these vents supports a wealth of biological activity. Following this theme, Hazen, George Cody, and Marilyn Fogel enlisted the help of Hatten Yoder and Yoder's high-pressure apparatus for a few experimental runs to assess how hydrothermal organic synthesis might provide insight to the problem of the origin of life. The effort led to promising results. Over the past several months, the group—expanded in numbers by many other researchers—have made several hundred more runs using a variety of compositions, pressures, and temperatures. It is too soon to know how successful the enterprise will be, but it is an excellent example of how the Carnegie modus operandi allows our scientists to exploit our resources and experience to attack an entirely new problem on short notice.

Boyd Symposium



Francis R. Boyd

Francis R. "Joe" Boyd retired in June 1996. In May 1997 we held a one-day symposium in his honor at the Lab. Many of Joe's old friends attended and gave talks related to his research, which covers a wide range of subjects but in recent years has focused on rocks (xenoliths) brought to Earth's surface by kimberlite eruptions. After the symposium, a dinner was held at a local hotel. Former Geophysical Laboratory postdoctoral fellow Steve Haggerty gave a fascinating talk, "Flambée Royal: Banqueting on Yggdrasil Diamond."

Summer Interns

For the past several years, we have conducted an informal summer program for high school and undergraduate students. This year we applied for and received a grant from the National Science Foundation to support the Carnegie Summer Intern Program in Geoscience. Eight undergraduates from universities and colleges across the country came to the Laboratory to participate in a variety of research projects. In addition, three high school students participated in the program. We all felt that this effort was very successful. The students contributed substantially to their individual projects, and we plan to continue the program next summer.

— Charles T. Prewitt

Geophysical Laboratory Personnel

July 1, 1996 – June 30, 1997

Research Staff

Francis R. Boyd, Jr., *Petrologist Emeritus*
George D. Cody
Ronald E. Cohen
Yingwei Fei
Larry W. Finger
Marilyn L. Fogel
John D. Frantz
P. Edgar Hare
Robert M. Hazen
Russell J. Hemley
T. Neil Irvine
Ho-kwang Mao
Bjørn O. Mysen
Charles T. Prewitt, *Director*
Douglas Rumble III
David Virgo
Hatten S. Yoder, Jr., *Director Emeritus*

Cecil and Ida Green Senior Fellow

Frank Press[1]

Senior Fellows and Associates

Peter M. Bell, *Adjunct Senior Research Scientist*
Constance Bertka, *Senior Research Associate, National Aeronautics and Space Administration (NASA) and Center for High Pressure Research (CHiPR)*
Paula Davidson, *Department of Energy (DOE) Associate*
Alexandre Goncharov, *Senior Research Associate (CHiPR)*[2]
Glenn A. Goodfriend, *Senior Postdoctoral Associate, National Science Foundation (NSF)*
Kei Hirose, *Tokyo Institute of Technology Fellow*[3]
Jingzhu Hu, *Research Technician (NSF)*
Jürgen Konzett, *Swiss National Science Foundation Fellow*[4]
Jinfu Shu, *Research Technician (CHiPR)*
Viktor Struzhkin, *Senior Research Associate (CHiPR)*[5]
Uwe Wiechert, *Deutsche Forschungsgemeinschaft Fellow*[6]
Chang-Sheng Zha, *Research Technician (CHiPR)*

Postdoctoral Fellows and Postdoctoral Research Associates

Richard D. Ash, *Smithsonian Institution and Carnegie Fellow*[7]
David R. Bell, *NSF Associate*
Jennifer Blank, *Carnegie Fellow, NSF/CHiPR Associate*[8]
Jay A. Brandes, *Carnegie Fellow*[9]
Robert T. Downs, *NSF Associate*[10]
James Farquhar, *Carnegie Fellow*
Daniel J. Frost, *CHiPR Associate*
Yoshiyuki Iizuka, *CHiPR Associate*[11]
Joel J. Ita, *NSF Associate*
Beverly Johnson, *Carnegie Fellow*[12]
Tahar Hammouda, *CNRS PICS and Carnegie Fellow*[13]
Victor Kress II, *CHiPR Associate*[14]
Wei Li, *CHiPR Associate*
Ren Lu, *NSF Associate*
William Minarik, *NSF Associate and Carnegie Fellow*[15]
Yanzhang Ma, *CHiPR Associate*[16]
Gotthard Sághi-Szabó, *Office of Naval Research Associate/CIW*
Thomas A. Schindelbeck, *Deutsche Forschungsgemeinschaft Fellow*
Guoyin Shen, *CHiPR Associate*[17] and *Grove Carl Gilbert Fellow*[18]
Madduri S. Somayazulu, *Carnegie Fellow*[19]
Mark A. Teece, *Barbara McClintock Fellow*[5]
Suzan van der Lee, *Harry Oscar Wood Fellow*[20]
Cecily J. Wolfe, *NASA Associate and Harry Oscar Wood Fellow*[21]
Hexiong Yang, *Hazen Gift*

Predoctoral Fellows and Predoctoral Research Associates

Pamela G. Conrad, *CHiPR Associate*
Julie Kokis, *NSF Associate*[13]
Jennifer Linton, *CHiPR Associate*[17]
Sean Shieh, *Carnegie Fellow*[22]
Fiorella Simoni, *NSF Associate*[23]
David M. Teter, *CHiPR Associate*[24]

Predoctoral Student

Catherine E. Shawl, *Northwestern University*[25]

Summer Interns, Geoscience Program (NSF)

AmyMane Accardi, *Rensselaer Polytechnic Institute, NY*[26]
Mark Acton, *Williams College, MA*[26]
Stephanie Kitchel, *State University of New York at Stony Brook*[26]
Nora Klein, *Brown University, RI*[26]
David Lawler, *Haverford College, PA*[26]
Vincent Lim, *University of Virginia*[26]
Audrey Slesinger, *Tufts University, MA*[26]
Michelle Weinberger, *University of Pennsylvania*[26]

Research Interns

Mark Acton, *Montgomery Blair High School*[27]
Rehan Ali, *Broad Run High School, Ashburn, VA*[27]
Aaron Andalman, *Stanford University*[28]
Benjamin Cooper, *Georgetown Day High School*[29]
Alexander M. Feldman, *Bethesda Chevy Chase High School*[30]
Maura Green, *Bethesda Chevy Chase High School*[28]
Marc Hudacsko, *University of Maryland*[28]
Eran Karmon, *Pomona College*[28]
Lisa McGill, *Cornell University*[28]
Sébastien Merkel, *École Normale Supérieure, Lyons, France*[28]
Virginie Pinel, *École Normale Supérieure, Lyons, France*[31]
Elizabeth Stranges, *Montgomery Blair High School*[28]
Jacob Waldbauer, *Georgetown Day School*[27]
Gamunu Wijetunge, *Montgomery Blair High School*[28]

Supporting Staff

John R. Almquist, *Library Volunteer*
Andrew J. Antoszyk, *Shop Foreman*
Alessandra Barelli, *Research Technician*[32]
Maceo T. Bacote, *Engineering Apprentice*[33]
Bobbie L. Brown, *Instrument Maker*
Stephen D. Coley, Sr., *Instrument Maker*
H. Michael Day, *Facilities Manager*[33]
Roy R. Dingus, *Building Engineer*[33]
Pablo D. Esparza, *Maintenance Technician*[33]
David J. George, *Electronics Technician*
Christos G. Hadidiacos, *Electronics Engineer*
Shaun J. Hardy, *Librarian*[33]
Marjorie E. Imlay, *Assistant to the Director*
William E. Key, *Building Engineer*[33]
Adriana Kuehnel, *Library Volunteer*[34]
D. Carol Lynch, *Executive Secretary*[35]
Paul Meeder, *Administrative Assistant*
Lawrence B. Patrick, *Maintenance Technician*[33]
Pedro J. Roa, *Maintenance Technician*[33]
Roy E. Scalco, *Engineering Apprentice*[33]
Susan A. Schmidt, *Coordinating Secretary*
John M. Straub, *Business Manager*
Mark Wah, *Instrument Maker*
Merri Wolf, *Library Technical Assistant*[33]

Visiting Investigators

Brigitte Behrends, *Deutsche Akademische Austauschdienst, Bonn*
Ben Burton, *National Institute of Standards and Technology*
Nabil Z. Boctor, *Washington, D. C.*
Alison Brooks, *George Washington University*
John V. Badding, *Pennsylvania State University*
C. Page Chamberlain, *Dept. Earth Sciences, Dartmouth College*
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Reto Gieré, *University of Basel, Switzerland*
Hans G. Huckenholz, *Mineralogisch-Petrographisches Inst. der Ludwig-Maximilians-Univ. Müchen*
Donald G. Isaak, *University of California, Los Angeles*
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Deborah Kelley, *University of Washington*
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Ryan P. McCormack, *National Institute of Standards and Technology*
Charles Meade, *National Research Council, Washington, D. C.*
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Qingchen Wang, *Chinese Academy of Sciences*
Hak Nan Yung, *Chinese Academy of Sciences*
Ru-Yuan Zhang, *Stanford University*
Yi-Gang Zhang, *Academia Sinica, China*
Guangtian Zou, *Jilin University, China*

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[1] To June 16, 1997
[2] From January 1, 1996
[3] From September 1, 1996
[4] From June 6, 1997
[5] From September 1, 1996
[6] From May 1, 1997
[7] From September 1996; joint appointment with DTM
[8] To December 31, 1996; From January 1 to June 30, 1997
[9] From December 6, 1996
[10] To July 31, 1996
[11] From September 26, 1996
[12] To October 1, 1996
[13] To June 30, 1996
[14] To August 12, 1996
[15] From January 28, 1997; joint appointment with DTM
[16] From August 1, 1996
[17] To August 31, 1997
[18] From September 1 to December 31, 1996; joint appointment with DTM
[19] From April 16, 1997
[20] From May 16, 1997; joint appointment withDTM
[21] To January 15, 1997; joint appointment with DTM
[22] From January 24, 1997
[23] To October 31, 1996
[24] To May 16, 1997
[25] From September 15 through December 31,1996
[26] From June 11, 1997
[27] From June 16, 1997
[28] To September 1, 1996
[29] From June 23, 1997
[30] From September 9, 1996 to May 30,1997
[31] From May 5, 1997
[32] To February 28, 1997
[33] Joint appointment with DTM
[34] From August 28, 1996; joint appointment with DTM
[35] To June 12, 1997; joint appointment with DTM

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Carnegie Administrative Personnel

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[1] To May 9, 1997
[2] From April 23, 1997
[3] To May 14, 1997
[4] From June 2, 1997
[5] To January 1, 1997

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[1] From July 1, 1996 to September 1, 1996, and from June 20, 1997
[2] From July 1, 1996 to September 1, 1996
[3] From June 20, 1997
[4] From June 15, 1997
[5] From July 1, 1996 to August 5, 1996

Carnegie Evening 1997

The institution's annual celebration of science, which traditionally kicks off the May meeting of the Board of Trustees, took place on the evening of Wednesday, May 7, at the Carnegie Building's Root auditorium. Carnegie Evening Lecturer Robert Hazen, staff member at the Geophysical Laboratory, gave a lecture entitled Carnegie Science and the Endless Frontier.

The Capital Science Lectures, sponsored by the institution with substantial support from Human Genome Sciences, the Johnson & Johnson Family of Companies, and the Schering-Plough Corporation, are held monthly during the academic year at the Carnegie Building in downtown Washington, D.C. The lectures are free and open to the public. Speakers also meet informally with groups of high school students. During the 1996-1997 year, the following lectures were given:

CAPITAL SCIENCE LECTURES

Microelectromechanical Systems (MEMS): It's the Little Things in Life That Keep You Going, by Susanne Arney (Bell Labs/Lucent Technologies), October 29, 1996

Finding and Forming Extrasolar Giant Planets and Brown Dwarfs, by Alan Boss (DTM, Carnegie Institution), November 19, 1996

Our Galaxy: Past, Present, and Future, by Vera Rubin (DTM, Carnegie Institution), December 17, 1996

Designing New Plants, by Christopher Somerville (Department of Plant Biology, Carnegie Institution), January 21, 1997

Infectious Disease: The War and Our Weaponry, by Richard Young (Whitehead Institute for Biomedical Research, MIT), February 18, 1997

The Earliest Life on Earth, by Lynn Margulis (University of Massachusetts), March 25, 1997

The Changing Ocean Climate, by Walter H. Munk (Scripps Institution of Oceanography, University of California), April 29, 1997

HIV and AIDS: Science Confronts an Epidemic, by William E. Paul (Office of AIDS Research, NIH), May 20, 1997


Christopher Somerville talking to high school students before his Capital Science Lecture

Publications of the President

Singer, M. F., Behind the Endless Frontier, in *AAAS Science and Technology Policy Yearbook 1996-1997*, A. Teich, S. Nelson, C. McEnaney, eds., American Association for the Advancement of Science, Washington, D.C., pp. 5-18, 1997.

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Maxine Singer

Financial Profile

Reader's Note: In this profile, references to spending levels or endowment amounts are on a cash or cash-equivalent basis. Therefore, the figures used do not reflect capitalization, depreciation, or other non-cash amounts.

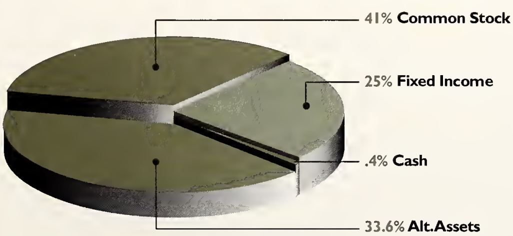
Carnegie Institution of Washington relies upon its endowment as the primary source of support for its activities. This reliance results in a fundamental independence in the conduct of the institution's scientific programs, both now and in the future. As of June 30, 1997, the endowment was valued at $382.9 million. It is allocated among a broad spectrum of assets that include fixed-income instruments (bonds), equities (stocks), arbitrage and distressed securities, real estate partnerships, private equity, and a hedge fund. Rather than manage these assets internally, the institution uses external managers and partnerships to carry out the investments, and it employs a commercial bank to maintain custody.

For the fiscal year ended on June 30, 1997, Carnegie's endowment had a total return (net of management fees) of 15.7%. The five-year running, total average return for the endowment was 13.8%.

The following chart shows the allocation of the institution's endowment among the asset classes it uses as of June 30, 1997:

	Target Allocation	Actual Allocation
Common Stock	40%	41%
Alternative Assets	35%	33.6%
Fixed Income	25%	25%
Cash	0%	0.4%

Actual Asset Allocation



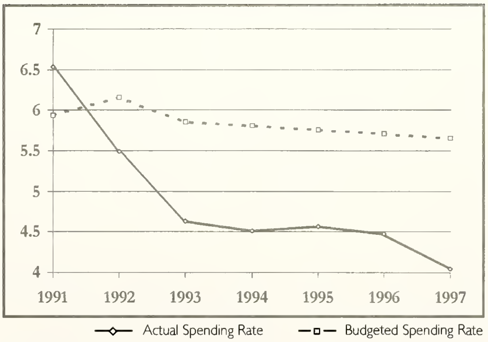
Carnegie's goal is to maintain the long-term spending power of its endowment. The result is a budgeting methodology that includes:

- averaging the total market value of the endowment for the three most recent fiscal years, and
- developing a budget that spends at a set percentage (spending rate) of this three-year market average.

During the 1990s, this budgeted spending rate has been declining in a phased reduction, moving towards an informal goal of 4.5%. For the 1997–1998 fiscal year, the rate was budgeted at 5.61%. While this budgeted rate has been declining at the rate of 5 basis points a year, there has been significant growth in the size of the endowment. The result has been that actual spending rates (the ratio of actual spending from the endowment to actual endowment value at the conclusion of the fiscal year in which the spending took place) declined to just over 4% for the year ended in June 1997.

The following table compares the planned versus the actual spending rates, as well as the market value of the endowment from 1990–1991 to the most recently concluded fiscal year, 1996–1997.

Budgeted and Actual Spending Rates



Within Carnegie's endowment, there are a number of "Funds" that provide support either in a general way or in a targeted way, with a specific, defined purpose. The Andrew Carnegie Fund is, by far, the largest of these. It was begun with the original gift of $10 million. Mr. Carnegie later added additional gifts totaling another $12 million during his lifetime. This fund is now valued at more than $306 million.

UNAUDITED

The following table shows the amounts in the principal funds within the institution's endowment as of June 30, 1997:

Market value of the Principal Funds Within Carnegie's Endowment

Andrew Carnegie	$306,565,521
Capital Campaign	24,950,439
Anonymous	9,067,698
Mellon Matching	6,954,368
Astronomy Funds	6,222,789
Anonymous Matching	5,792,462
Carnegie Futures	5,087,641
Wood	4,041,734
Golden	2,364,342
Bowen	1,927,430
Colburn	1,618,119
McClintock	1,201,113
Special Instrumentation	861,610
Bush Bequest	744,309
Moseley Astronomy	642,216
Special Opportunities	568,400
Starr Fellowship	424,812
Roberts	330,801
Lundmark	259,578
Morgenroth	192,091
Hearst Educational Fund	183,452
Hollaender	178,960
Bush	126,473
Moseley	113,495
Forbush	107,813
Green	76,725
Hale	70,518
Harkavy	68,344
Other	4,455
Total	**$380,747,708**

End of Financial Profile

Financial Statements and Schedule

June 30, 1997 and 1996

Independent Auditors' Report

To the Auditing Committee of the Carnegie Institution of Washington:

We have audited the accompanying statements of financial position of the Carnegie Institution of Washington (Carnegie) as of June 30, 1997 and 1996, and the related statements of activities and cash flows for the years then ended. These financial statements are the responsibility of the Institution's management. Our responsibility is to express an opinion on these financial statements based on our audits.

We conducted our audits in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of the Carnegie Institution of Washington as of June 30, 1997 and 1996, and its changes in net assets and its cash flows for the years then ended, in conformity with generally accepted accounting principles.

Our audits were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supplementary information included in Schedule 1 is presented for purposes of additional analysis and is not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the audit of the basic financial statements and, in our opinion, is fairly presented in all material respects in relation to the basic financial statements taken as a whole.

As described in note 7 to the financial statements, Carnegie adopted the provisions of Statement of Financial Accounting Standards No. 106, Employers' Accounting for Postretirement Benefits Other Than Pensions in 1996.

KPMG Peat Marwick LLP

October 8, 1997

Statement of Financial Position

June 30, 1997 and 1996

Assets	1997	1996
Cash and cash equivalents	$ 2,759,057	97,012
Accrued investment income	477,140	867,735
Contributions receivable (note 2)	3,773,587	2,622,740
Accounts receivable and other assets	2,007,377	2,219,112
Bond proceeds held by trustee (note 5)	11,159,876	15,032,558
Investments (note 3)	380,747,708	362,041,971
Construction in progress (note 4)	28,737,444	23,413,297
Property and equipment, net (note 4)	37,880,114	38,282,583
	$ 467,542,303	**444,577,008**
Liabilities and Net Assets		
Accounts payable and accrued expenses	$ 2,068,094	2,519,359
Deferred revenues	1,149,050	1,247,330
Broker payable (note 3)	-	23,752,995
Bonds payable (note 5)	34,769,596	34,732,731
Accrued postretirement benefits (note 6)	9,236,983	8,660,871
Total liabilities	47,223,723	70,913,286
Net assets (note 7):		
Unrestricted:		
Board designated:		
Invested in fixed assets, net	31,847,962	26,963,149
Designated for managed investments	331,472,827	298,055,655
Undesignated	6,728,893	6,813,171
	370,049,682	331,831,975
Temporarily restricted	15,586,090	9,487,485
Permanently restricted	34,682,808	32,344,262
Total net assets	420,318,580	373,663,722
Commitments and contingencies (notes 8, 9, and 10)		
Total liabilities and net assets	**$ 467,542,303**	**444,577,008**

See accompanying notes to financial statements.

Statement of Activities

Years ended June 30, 1997 and 1996

	1997				1996			
	Unrestricted	Temporarily restricted	Permanently restricted	Total	Unrestricted	Temporarily restricted	Permanently restricted	Total
Program and supporting services expenses:								
Terrestrial Magnetism	$ 5,481,263	-	-	5,481,263	4,948,551	-	-	4,948,551
Observatories	5,595,168	-	-	5,595,168	5,601,435	-	-	5,601,435
Geophysical Laboratory	5,648,244	-	-	5,648,244	5,963,455	-	-	5,963,455
Embryology	5,097,677	-	-	5,097,677	4,366,256	-	-	4,366,256
Plant Biology	4,450,109	-	-	4,450,109	4,278,272	-	-	4,278,272
Other Programs	943,838	-	-	943,838	972,927	-	-	972,927
Administrative and general expenses	2,565,202	-	-	2,565,202	2,962,056	-	-	2,962,056
Total expenses	29,781,501	-	-	29,781,501	29,092,952	-	-	29,092,952
Revenues and support:								
Grants and contracts	10,340,760	-	-	10,340,760	10,143,786	-	-	10,143,786
Contributions and gifts	740,031	6,058,154	2,220,044	9,018,229	212,159	3,354,873	1,244,592	4,811,624
Net gain (loss) on disposals of property	(60,694)	-	-	(60,694)	3,480,506	-	-	3,480,506
Other income	623,102	-	-	623,102	650,021	-	-	650,021
Net external revenue	11,643,199	6,058,154	2,220,044	19,921,397	14,486,472	3,354,873	1,244,592	19,085,937
Investment income (note 3)	53,009,113	3,387,347	118,502	56,514,962	44,521,860	2,208,597	89,818	46,820,275
Net assets released from restrictions (note 7)	3,346,896	(3,346,896)	-	-	3,080,371	(3,080,371)	-	-
Total revenues, gains, and other support	67,999,208	6,098,605	2,338,546	76,436,359	62,088,703	2,483,099	1,334,410	65,906,212
Increase in net assets before cumulative effect of change in accounting for postretirement benefits	38,217,707	6,098,605	2,338,546	46,654,858	32,995,751	2,483,099	1,334,410	36,813,260
Cumulative effect of change in accounting for postretirement benefits (note 6)	-	-	-	-	(8,129,000)	-	-	(8,129,000)
Increase in net assets	38,217,707	6,098,605	2,338,546	46,654,858	24,866,751	2,483,099	1,334,410	28,684,260
Net assets at the beginning of the year	331,831,975	9,487,485	32,344,262	373,663,722	306,965,224	7,004,386	31,009,852	344,979,462
Net assets at the end of the year	**$ 370,049,682**	**15,586,090**	**34,682,808**	**420,318,580**	**331,831,975**	**9,487,485**	**32,344,262**	**373,663,722**

See accompanying notes to financial statements.

Statement of Cash Flows

Years ended June 30, 1997 and 1996

	1997	1996
Cash flows from operating activities:		
Increase in net assets	$ 46,654,858	28,684,260
Adjustments to reconcile increase in net assets to net cash provided by operating activities:		
Depreciation	2,458,035	2,425,292
Net gains on investments	(45,740,779)	(37,297,991)
Loss (gain) on disposal of property	60,694	(3,480,506)
Amortization of bond issuance costs and discount	36,865	36,864
Contribution of stock	(1,499,164)	-
(Increase) decrease in assets:		
Receivables	(939,112)	358,122
Accrued investment income	368,324	(103,764)
Increase (decrease) in liabilities:		
Accounts payable and accrued expenses	(451,265)	(1,318,884)
Deferred revenues	(98,279)	995,281
Accrued postretirement benefits	576,112	8,660,871
Contributions and investment income restricted for long-term investment	(5,233,565)	(2,085,846)
Net cash used by operating activities	(3,807,276)	(3,126,301)
Cash flows from investing activities:		
Draws from bond proceeds held by trustee	3,872,682	4,614,925
Acquisition of property and equipment	(2,116,260)	(1,569,960)
Proceeds from sale of land and buildings	-	3,780,673
Construction of telescope, facilities, and equipment	(5,324,147)	(8,408,479)
Investments purchased, net of change in broker payable of ($23,752,995) and $13,021,309	(436,911,531)	(390,613,647)
Proceeds from investments sold or matured	441,715,012	393,114,394
Net cash provided by investing activities	1,235,756	917,906
Cash flows from financing activities – proceeds from contributions and investment income restricted for:		
Investment in endowment	2,497,544	921,635
Investment in property and equipment	2,736,021	1,164,211
Net cash provided by financing activities	5,233,565	2,085,846
Net increase (decrease) in cash and cash equivalents	2,662,045	(122,549)
Cash and cash equivalents at the beginning of the year	97,012	219,561
Cash and cash equivalents at the end of the year	**$ 2,759,057**	**97,012**
Supplementary cash flow information:		
Cash paid for interest	**$ 1,622,971**	**1,638,829**

See accompanying notes to financial statements.

Notes to Financial Statements

June 30, 1997 and 1996

(1) Organization and Summary of Significant Accounting Policies

Organization

The Carnegie Institution of Washington (Carnegie) conducts advanced research and training in the sciences. It carries out its scientific work in five research centers located throughout the United States and an observatory in Chile. They are the Departments of Embryology, Plant Biology, and Terrestrial Magnetism, the Geophysical Laboratory, and the Observatories (astronomy). Carnegie's external income is mainly from gifts and federal grants and contracts. In addition, income from investments represents approximately 70 percent of Carnegie's total revenues.

Basis of Accounting and Presentation

The financial statements are prepared on the accrual basis of accounting. Expenses are separately reported for major programs and administrative and general expenses. Revenues are classified according to the existence or absence of donor-imposed restrictions. Also, satisfaction of donor-imposed restrictions are reported as releases of restrictions in the statements of activities.

Investments and Cash Equivalents

Carnegie's debt and equity investments are reported at their fair values. Carnegie also reports investments in partnerships at fair value as determined and reported by the general partners. All changes in fair value are recognized in the statement of activities. Carnegie considers all highly liquid debt instruments purchased with remaining maturates of 90 days or less to be cash equivalents.

Income Taxes

Carnegie is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code (the Code). Accordingly, no provision for income taxes is reflected in the accompanying financial statements. Carnegie is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified Carnegie as other than a private foundation, as defined in Section 509(a) of the Code.

Fair Value of Financial Instruments

Financial instruments of Carnegie include cash equivalents, receivable, investments, bond proceeds held by trustee, accounts and broker payables, and bonds payable. The fair value of investments in debt and equity securities is based on quoted market prices. The fair value of investments in limited partnerships is based on information provided by the general partners.

The fair value of Series A bonds payable is based on quoted market prices. The fair value of Series B bonds payable is estimated to be the carrying value, since these bonds bear adjustable market rates.

The fair values of cash equivalents, receivable, and accounts and broker payable approximate their carrying values based on their short maturates.

Use of Estimates

The preparation of financial statements in conformity with generally accepted accounting principles requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements. They also affect the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Property and Equipment

Carnegie capitalizes expenditures for land, buildings and leasehold improvements, telescopes, scientific and administrative equipment, and projects in progress. Routine replacement, maintenance, and repairs are charged to expense.

Depreciation is computed on a straight-line basis over the following estimated useful lives:

Buildings and telescopes	50 years

Leasehold improvements	lesser of 25 years or the remaining term of the lease
Scientific and administrative equipment	5 years

Contributions

Contributions are classified based on the existence of donor-imposed restrictions. Contributions and net assets are classified as follows:

Unrestricted - includes all contributions received without donor-imposed restrictions on use or time.

Temporarily restricted - includes contributions with donor-imposed restrictions as to purpose of gift or time period expended.

Permanently restricted - generally includes endowment gifts in which donors stipulated that the corpus be invested in perpetuity. Only the investment income generated from endowments may be spent. Certain endowments require that a portion of the investment income be reinvested in perpetuity.

Gifts of long-lived assets, such as buildings or equipment, are considered unrestricted when placed in service.

Grants

Carnegie records revenues on grants from federal agencies only to the extent that reimbursable expenses are incurred. Accordingly, funds received in excess of reimbursable expenses are recorded as deferred revenue, and expenses in excess of reimbursements are recorded as accounts receivable. Reimbursement of indirect costs is based upon provisional rates which are subject to subsequent audit by Carnegie's federal cognizant agency, the National Science Foundation.

Reclassifications

Certain prior year amounts were reclassified to conform to the current year presentation.

(2) Contributions Receivable

Contributions receivable are summarized as follows at June 30, 1997:

Unconditional promises expected to be collected in years ended June 30	
1998	$ 2,218,309
1999	1,264,917
2000	94,515
2001	81,955
2002	27,000
2003 and later	86,891
	$ 3,773,587

(3) Investments

At June 30, 1997 and 1996, investments at fair value consisted of the following:

	1997	1996
Time deposits and money market funds	$ 18,488,606	37,341,690
Debt mutual funds	65,150,721	8,399,448
Debt securities	24,122,834	73,344,086
Equity securities	144,759,793	143,155,883
Real estate partnerships	39,657,484	25,385,382
Limited partnerships	88,568,270	74,415,482
	$ 380,747,708	**362,041,971**

Investment income for the years ended June 30, 1997 and 1996, consisted of the following:

	1997	1996
Interest and dividends	$ 11,744,238	10,398,641
Net realized gains	26,527,556	23,076,251
Net unrealized gains	19,213,223	14,217,243
Less - investment management expenses	(970,055)	(871,860)
	$ 56,514,962	**46,820,275**

Carnegie purchased and sold certain investment securities on dates prior to June 30, 1996. These trades were settled subsequent to June 30, 1996,

and are reflected in the investment balances reported at year end. The net obligation for these unsettled trades is reported as broker payable in the accompanying statements of financial position.

The fair value for approximately $21 million of Carnegie's $128 million of real estate and limited partnership investments has been estimated by the general partners in the absence of readily ascertainable market values. However, the estimated fair values may differ from the values that would have been used had a ready market existed.

Carnegie enters into futures contracts to manage portfolio positions and hedge transactions. Risks relating to futures contracts arise from the movements in securities values and interest rates. Realized gains and losses based on changes in market values of open futures contracts have been fully recognized. The contracts are settled daily for changes in their fair value. Accordingly, the fair value of the contracts at June 30, 1997 and 1996, is zero. The total notional value of these contracts at June 30, 1997 and 1996 was approximately $3,500,000 and $4,500,000, respectively.

(4) Property and Equipment

At June 30, 1997 and 1996, property and equipment placed in service consisted of the following:

	1997	1996
Buildings and improvements	$ 34,660,342	34,037,604
Scientific equipment	14,736,201	13,593,569
Telescopes	7,910,825	7,910,825
Administrative equipment	2,316,444	2,163,650
Land	787,896	787,896
Art	34,067	34,067
	60,445,775	58,527,611
Less accumulated depreciation	22,565,661	20,245,028
	$ 37,880,114	**38,282,583**

At June 30, 1997 and 1996, construction in progress consisted of the following:

	1997	1996
Telescope	$ 26,924,587	21,741,034
Buildings	1,523,337	1,355,800
Scientific equipment	289,520	316,463
	$ 28,737,444	23,413,297

At June 30, 1997 and 1996, approximately $34 million and $28 million, respectively, of construction in progress and other property, net of accumulated depreciation, was located in Las Campanas, Chile. During 1997 and 1996, Carnegie capitalized net interest costs of approximately $1,154,000 and $745,000, respectively, as construction in progress.

(5)Bonds Payable

On November 1, 1993, Carnegie issued $17.5 million each of secured Series A and Series B California Educational Facilities Authority Revenue tax-exempt bonds. Bond proceeds are used to finance the Magellan telescope project and the renovation of the facilities of the Observatories at Pasadena. The balances outstanding at June 30, 1997 and 1996, on the Series A issue totaled $17,357,224 and $17,334,380, respectively, and on the Series B issue totaled $17,412,372 and $17,398,351, respectively. The balances outstanding are net of unamortized bond issue costs and bond discount. Bond proceeds held by the trustee and unexpended at June 30, 1997 and 1996, totaled $11,159,876 and $15,032,558, respectively.

Series A bonds bear interest at 5.6 percent payable in arrears semiannually on each April 1 and October 1 and upon maturity on October 1, 2023. Series B bonds bear interest at variable money market rates in effect from time to time, up to a maximum of 12 percent over the applicable money market rate period of between one and 270 days and have a stated maturity of October 1, 2023. At the end of each money market rate period, Series B

bondholders are required to offer the bonds for repurchase at the applicable money market rate. If repurchased, the Series B bonds would be resold at the current applicable money market rate and for a new rate period.

Carnegie is not required to repay the Series A and B bonds until the October 1, 2023, maturity date, and Carnegie has the intent and the ability to effect the purchase and resale of the Series B bonds through a tender agent; therefore all bonds payable are classified as long term. Sinking fund redemptions begin in 2019 in installments for both series. The fair value of Series A bonds payable at June 30, 1997 and 1996, based on quoted market prices is estimated at $18,300,000 and $17,600,000, respectively. The fair value of Series B bonds payable at June 30, 1997 and 1996, is estimated to approximate carrying value as the mandatory tender dates on which the bonds are repriced are generally within three months of year end.

(6)Employee Benefit Plans

Retirement Plan

Carnegie has a noncontributory, defined contribution, money-purchase retirement plan in which all United States personnel are eligible to participate. After one year's participation, an individual's benefits are fully vested. The Plan has been funded through individually owned annuities issued by Teachers' Insurance and Annuity Association (TIAA) and College Retirement Equities Fund (CREF). There are no unfunded past service costs. Total contributions made by Carnegie totaled approximately $1,783,000 and $1,737,000 for the years ended June 30, 1997 and 1996, respectively.

Postretirement Benefits Plan

Carnegie provides postretirement medical benefits to all employees who retire after age 55 and have at least ten years of service. Prior to 1996, the cost of postretirement benefits was charged to expense only on a cash basis (pay-as-you-go). Cash payments made by Carnegie for these benefits totaled approximately $374,000 and $398,000 for the years ended June 30, 1997 and 1996, respectively.

Effective July 1, 1995, Carnegie adopted SFAS No. 106, *Employers' Accounting for Postretirement Benefits Other Than Pensions,* and changed its method of accounting for postretirement benefits from a cash basis to an accrual basis. This accounting change resulted in a one-time, noncash expense in 1996 of approximately $8,129,000 for the transition obligation. The transition obligation represents the fully recognized actuarially determined estimate of Carnegie's obligation for postretirement benefits as of July 1, 1995. The expense for postretirement benefits in 1997 and 1996 under the provisions of SFAS No. 106 was approximately $950,000 and $930,000, respectively. The 1997 postretirement benefits expense was approximately $576,000 more than the cash expense of $374,000, and the 1996 postretirement benefits expense was approximately $532,000 more than the cash expense of $398,000. The postretirement benefits expense was allocated among program and supporting services expenses in the statements of activities.

The following items are the components of the net postretirement benefit cost for the years ended June 30, 1997 and 1996:

	1997	1996
Service cost - benefits earned during the year	$ 314,000	335,000
Interest cost on projected benefit obligation	636,000	595,000
	$ 950,000	**930,000**

The following table sets forth the funded status of the postretirement medical benefits plan as of June 30, 1997 and 1996:

	1997	1996
Actuarial present value of the accumulated postretirement benefit obligation for:		
Inactive participants	$ 4,618,000	4,541,000
Fully eligible active participants	2,012,000	1,828,000
Other active participants	2,647,000	2,025,000
Accumulated postretirement benefit obligation for services rendered to date	9,277,000	8,394,000
Unrecognized net (gain) loss	(40,000)	267,000
Accrued postretirement benefit cost	**$9,237,000**	**8,661,000**

The present value of the transition obligation as of July 1, 1995, was determined using an assumed health care cost trend rate of 10 percent and an assumed discount rate of 7.5 percent. The present value of the benefit obligation as of June 30, 1997 and 1996, was determined using an assumed health care cost trend rate of 10 percent and an assumed discount rate of 7.5 percent. Carnegie's policy is to fund postretirement benefits as claims and administrative fees are paid.

For measurement purposes, a 10 percent annual rate of increase in the per capita cost of covered health care benefits was assumed for 1997; the rate was assumed to decrease gradually to 5.5 percent in 15 years and remain at that level thereafter. The health care cost trend rate assumption has a significant effect on the amounts reported. An increase of 1.0 percent in the health care cost trend rate used would have resulted in a $1,458,000 increase in the present value of the accumulated benefit obligation at June 30, 1997, and a $189,000 increase in the aggregate of service and interest cost components of net periodic postretirement benefit cost for the year ended June 30, 1997.

(7) Net Assets

At June 30, 1997 and 1996, temporarily restricted net assets were available to support the following donor-restricted purposes:

	1997	1996
Specific research programs	$ 8,225,980	6,076,025
Equipment acquisition and construction	7,360,110	3,411,460
	$ 15,586,090	**9,487,485**

At June 30, 1997 and 1996, permanently restricted net assets consisted of permanent endowments, the income from which is available to support the following donor-restricted purposes:

	1997	1996
Specific research programs	$ 11,478,089	9,139,543
Equipment acquisition and construction	1,204,719	1,204,719
General support (Carnegie endowment)	22,000,000	22,000,000
	$ 34,682,808	**32,344,262**

During 1997 and 1996, Carnegie met donor-imposed requirements on certain gifts and, therefore, released temporarily restricted net assets as follows:

	1997	1996
Specific research programs	$ 2,364,853	2,220,653
Equipment acquisition and construction	982,043	859,718
	$ 3,346,896	**3,080,371**

(8)Federal Grants and Contracts

Costs charged to the federal government under cost-reimbursement grants and contracts are subject to government audit. Therefore, all such costs are subject to adjustment. Management believes that adjustments, if any, would not have a significant effect on the financial statements.

(9)Commitments

In 1992, Carnegie entered into a 30-year collaborative agreement with the University of Arizona for the construction, installation, and operation of a large aperture telescope in Chile (Magellan project). The agreement requires the University of Arizona to manufacture and deliver a primary mirror to be used in the Magellan project for $6.35 million, subject to adjustment. The telescope is currently under construction. Carnegie and the University of Arizona have agreed to share use of the telescope until expiration of the agreement in 2022. Telescope viewing time and annual operating costs will be shared by the two parties in amounts proportional to the parties' capital contributions.

During 1996, Carnegie entered into memoranda of understanding with three other universities to expand the scope of the Magellan project. These memoranda provide for the creation of a consortium to discuss construction of a second telescope, and define a formula by which consortium members will share capital and operating costs. Advance payments received from these universities totaling approximately $859,400 and $537,000 as of June 30, 1997 and 1996, respectively, have been classified as deferred revenue in the accompanying statements of financial position.

Carnegie has outstanding commitments to invest approximately $11.5 million in limited partnerships.

(10) Lease Arrangements

Carnegie leases a portion of the land it owns in Las Campanas, Chile to other organizations. These organizations have built and operate telescopes on the land. Most of the lease arrangements are not specific and some are at no-cost to the other organizations. One of the lease arrangements is noncancelable and has annual future rents of $120,000 through fiscal year 2001. For the no-cost leases, the value of the leases could not be determined and is not considered significant, and, accordingly, contributions have not been recorded in the financial statements.

Carnegie also leases a portion of one of its laboratories to another organization for an indefinite term. Rents to be received under the agreement are approximately $183,000 annually, adjusted for CPI increases.

Carnegie leases land and buildings. The monetary terms of the leases are considerably below fair value, however these terms were developed considering other non-monetary transactions between Carnegie and the lessors. The substance of the transactions indicates arms-length terms between Carnegie and the lessors. The monetary value of the leases could not be determined, and has not been recorded in the financial statements.

(11) Subsequent Events

Subsequent to the date of the financial statements, Carnegie entered into an agreement with a contractor for the renovation of Carnegie's headquarters building. The expected maximum price under the agreement for the renovations is approximately $5,400,000 subject to change orders.

Also subsequent to the date of the financial statements, Carnegie entered into a contract with the University of Arizona for the construction of the primary mirror and support system for the second telescope in the Magellan project. The amount of the contract is approximately $9,700,000.

Schedules of Expenses

Schedule 1

Years ended June 30, 1997 and 1996

	1997			1996		
	Carnegie funds	Federal and private grants	Total expenses	Carnegie funds	Federal and private grants	Total expenses
Personnel costs:						
Salaries	$ 9,763,705	2,972,498	12,736,203	9,639,148	2,832,044	12,471,192
Fringe benefits and payroll taxes	3,616,358	800,952	4,417,310	3,627,649	765,818	4,393,467
Total personnel costs	13,380,063	3,773,450	17,153,513	13,266,797	3,597,862	16,864,659
Fellowship grants and awards	1,360,445	647,853	2,008,298	1,112,780	677,741	1,790,521
Depreciation	2,458,035	-	2,458,035	2,425,292	-	2,425,292
General expenses:						
Educational and research supplies	798,925	1,060,501	1,859,426	698,865	1,069,139	1,768,004
Building maintenance and operation	1,744,184	387,676	2,131,860	2,146,073	281,870	2,427,943
Travel and meetings	560,818	509,570	1,070,388	551,412	481,078	1,032,490
Publications	32,348	79,656	112,004	26,066	65,912	91,978
Shop	46,262	-	46,262	82,505	-	82,505
Telephone	176,209	385	176,594	174,877	94	174,971
Books and subscriptions	231,418	6,278	237,696	209,073	4,666	213,739
Administrative and general	515,693	51,277	566,970	520,234	67,304	587,538
Printing and copying	216,664	5,239	221,903	113,247	1,137	114,384
Shipping and postage	108,851	39,494	148,345	99,362	24,114	123,476
Insurance, taxes and professional fees	919,764	116,960	1,036,724	660,148	125,525	785,673
Equipment	13,673	816,397	830,070	16,322	1,079,699	1,096,021
Fund-raising expense	338,380	-	338,380	312,116	-	312,116
Total general expenses	5,703,189	3,073,433	8,776,622	5,610,300	3,200,538	8,810,838
Indirect costs – grants	(2,846,024)	2,846,024	-	(2,667,645)	2,667,645	-
Capitalized scientific equipment and construction projects funded by Federal and private grants	(614,967)	-	(614,967)	(798,358)	-	(798,358)
	$ 19,440,741	**10,340,760**	**29,781,501**	**18,949,166**	**10,143,786**	**29,092,952**

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A GIFT FOR THE FUTURE OF THE

CARNEGIE INSTITUTION

OF WASHINGTON

One of the most effective ways of supporting the work of the Carnegie Institution of Washington is to include the institution in your estate plans. By making a bequest, you can support the institution well into the future.

A bequest is both a tangible device of your dedication to the Carnegie Institution and a way to generate significant tax savings for your estate. Some bequests to the institution have been directed to fellowships, chairs, and departmental research projects; some have been additions to the endowment; other bequests have been unrestricted.

The following sample language can be used in making a bequest to the Carnegie Institution:

"I give, and bequeath the sum of $_____ (or % of my residuary estate) to the Carnegie Institution of Washington, 1530 P Street, N.W., Washington, DC 20005-1910."

For additional information, please call Susanne Garvey, Director of External Affairs, at 202.939.1128, or write:

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